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PHYSIOLOGY

EXHAUSTIVE AND PRACTICAL.

A SERIES OF PRACTICAL LECTURES DELIVERED FROM DAY TO DAY BY

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IN THE

AMERICAN SCHOOL OF OSTEOPATHY

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PREFACE.

THE publication of "Physiology, Exhaustive and Practical" in its present form is due to a continued manifestation of interest in, and a high appreciation of the value of these lectures as delivered by Prof. Littlejohn, in his daily work.

Many students who, at first, thought them beneficial only for special preparation on the different subjects, now consider them more valuable for future reference and desire to preserve the same in a handsomely bound form and give them a permanent place in their libraries.

And to the end that these "nuggets of pure gold" may be properly treasured, I commend this volume to my fellow students, and would be glad to have their criticisms, as well as suggestions.

I desire to acknowledge valuable suggestions from numerous students and invaluable aid, in the preparation of this work, from Dr. J. M. Littlejohn.

I wish to thank the publishers for the extreme care they have exercised in the mechanical execution of the work.

H. R. BYNUM.

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PART I.

INTRODUCTION.

In beginning the study of Physiology we must always remember that all Science is one and that there is unity in Science that specialization cannot dispense with.

When we abstract we tend to narrowness and bigotry. Science literally means knowledge, and it covers the whole field of knowledge but it also implies exactness of knowledge based upon observation, experiment and classification.

Observation and experimentation furnish the basal facts which are reasoned about and reduced to unity and system in the form of ideas; these ideas in turn forming the basis upon which science is systematically built up. Physiology is a part of science and a very essential part. Physiology literally means, from phusis and logos, reasoning about nature, in this case, limited to human nature, at least, in the field of human Physiology. Every form of life has a Physiology, so that Physiology really falls baek upon Biology as the Primary Science. Biology is the Science of life in general. Physiology is the Science that reasons about the nature of life, its modes of activity and the actions of its organisms. In other words, it is the science of organized life. Morphology as distinguished from Physiology deals with the form and structure of living beings. Life, itself, from this standpoint, is that science of relations, physical, chemical and vital which gives us certain phenomena that we characterize as manifestations of vitality. This, of course, implies behind all phenomena the life principle.

Anatomy, Physiology and Pathology are the three great pillars upon which rests the Science of Medicine. The Science of Medicine is not limited to the prescription, and knowledge of Drugs or Physic; this is the degenerated idea of Medicine. The Science of Medicine deals with the preservation and prolongation of human life and with the curing of those abnormal conditions which tend to weaken or destroy life. Medicine in its history nas followed several curative principles. Primitively associated with priestcraft, it consisted of certain ceremonial observances. Later it consisted of certain charms which the superstitious character of the people encouraged. To this day certain forms and incantations are believed to possess medicinal virtue. In the definition of the Science I have given, I think it is wide enough to cover Osteopathy, because I believe Osteopathy is a part of the Science of Medicine and Osteopathy should claim the word Medicine in its original sense, namely, that of healing. There are three great fields of knowledge in the Science of Medicine—Anatomy, Physiology and Pathology. Anatomy is the Science of organization or of the structure of the human system. Physiology is the science of organized life in its various functions. Pathology is the science which deals with abnormal conditions of human life. Symtomatology is the science which deals with results from the standpoint of Physiology and Pathology combined, with symptoms or signs of diseased conditions viewed from the standpoint of the expert physician who has a correct knowledge of Anatomy, Physiology and Pathology. To combat disease and consequently to prevent death we must have

a thorough knowledge of these sciences. These represent the normal con ditions and also the abnormal conditions. To understand and meet the unhealthful conditions we must know the healthful and health-giving conditions and functions. Physiology forms the middle science in this trinity of sciences and is a most essential study in the field of Medicine. But there is a wider field in which Physiology figures. Physiology has not only a bearing upon Medicine but also upon Psychology and through Psychology upon the whole field of education. Physiology explains and largely accounts for Psychological conditions; for true Psychology is founded on Physiology. The mental states and activities are of value only as the illustrations of Psychological relations and conditions. The psychic conditions of life are brought out not alone in the field of education, in adaptations to study but also in the study and diagnosis of mental diseases, and many of the nervous diseases. The Physiology of the brain, spinal cord and of the entire nervous system is at the foundation of every true theory of life, whether we take it in regard to physical life, in its preservation, prolongation and its treatment under diseased conditions or in regard to mental life and even the higher moral and spiritual life.

A correct knowledge of Physiology applied in the field of Psychology has rendered obsolete older ideas and plans of education and has given rise to the modern natural school of education that has done so much to evolve didactic principles and plans for educating that is leading out and up the mind to the realms of knowledge rather than piling in the material into an already overcrowded mind. May we not look for the same reform in the field of medicine when Physiology is taught in all its bearings as it teaches the true functions of a differentiated human life consisting of a number of organs all of which are independent, and yet are united to form a single life. As we step into the higher field of Psycho-physiology, we realize the fact that mind is the ascendant power and that in a healthy physical life nothing less than a healthy mind can secure that vigorous condition of body so much desired by all. We realize also that while we treat purely bodily diseases we must not overlook the fact that Psycho-pathy partly discloses mental diseases and mind conditions without the removal of which it is impossible to cure bodily diseases. This wide field we believe is opened before Osteopathy and we think that our claim is not too great when we say in beginning this course of Physiology that Physiology is the gateway by which this immense field is to be entered. In its bearings upon the human life with all its functions we constantly remember that it is our purpose in teaching Physiology, to lead your minds up to that high standard of knowledge regarding Physiology which will qualify you to become efficient operators in the field of Osteopathy.

PHYSIOLOGY.

Physiology treats of organized and functional life. Human Physiology treats of the vital actions and functions of the various parts of the human system. In general it treats of the actions and the uses ot the various parts of the living body. Everything that has life has a physiology; hence, we have vegetable, animal comparative and human Physiology. Vegetable Physiology is brought out in the science of Botany. Animal Physiology is both comparative and human and embraces the whole animal kingdom. Comparative Physiology deals with the life of the inferior races of animals. Human Physiology teaches of the various organs of the human body. In order to understand Physiology, the construction and composition of the human body must be understood. The properties or relations of the human body are chemical, physical and vital. These relations when harmoniously sustained through a succession of time constitute life from a physiological standpoint. Life consists of the manifestations of certain phenomena, depending upon these three properties. One of these manifestations is activity back of which is the will and the mind. We have much to say of life, or vital activity, but the most that we know of it is its results. What life is and its exact position in relation to what we call the body is not known. All the parts of the body are united together by a wonderful sympathy and manifest united activity. The human body is an organism, that is, each part of the human body is both cause and effect in its relation to organism as a whole; this organism of the human body is differentiated into different parts or organs which discharge their own peculiar functions, all the different parts being united so as to constitute the single human body and the individual life. The three basic principles or elements of the human system are matter, motion and mind. These are called the trinity of operations in the human system. They are named in their order from the standpoint of result and of development from the standpoint of Science. We do not speak here of any first cause of these elements, we are not concerned with causation because that belongs to metaphysics. In Scienee we find these as facts and we deal with them as results. The lowest substratum of all development is matter; hence, Physics and Chemistry begin by discussing the fundamental properties of matter. Biology discusses the same properties in connection with life and the energy of life. Life, so far as known to us, exists solely as a manifestation of living matter the result of certain underlying causes, these causes manifesting themselves in activity through the human body and mind. Although living matter and lifeless matter are entirely distinct, yet they are closely related. Matter is constantly being taken into the body and transformed into the body substance by the functions of assimilation, absorption, etc. The living substance of the human body is the transmuted lifeless matter of food which has been taken into the body and has become animalized. The continuance of life depends upon the assimilation of this lifeless matter with the life substance of the body.

The theory of life in its continuance is that of the relation between living matter and lifeless matter and the great question is, how to accomplish this process of assimilation. The body is a living mould into which certain substances are cast to be assimilated into the system and the waste matters expelled. Prof. Huxley has said: "The living organism is in a constant state of turmoil in connection with material molecules constantly streaming into the body and out again." The second factor of life is motion. Matter is associated with motion because all life in matter is a form of motion. The living substance of the body is a compound of certain chemical elements. This living substance contains what are known as proteids. These compounds are composed of O, H, N, C, and sometimes at least, S and P. These proteids constitute the material substratum of the human body. Each of these elements has a peculiar characteristic; O has the power of combination, H has the power of mobility, N has the inertial power, so that in the complex compound the strongest properties are allied to constitute a human, material body. The material substratum of the human body is thus found to be proteids; these proteids affecting the chemical and mechanical processes of the human body.

There are not only material substances in the human body, but also power, capacity, function or energy. The living substance of the body has the power to manufacture new substances out of those substances taken into the body. This process of manufacturing, roughly speaking, represents the process by which the body organism renews itself for a continuance of life. The process of combustion goes on continuously producing heat which is converted into energy and motion. The bodily substance is constantly wasting away by this combustion process, and hence, needs constantly to be repaired. The repairs in the human system are effected by the characteristic development of the human body, known as intersusception, that is the power of taking in new particles and assimilating them to the bodily substance. In general there are three great functions in the development of the human system.

1st. Nutrition including assimilation or taking in and animalizing particles and nutrition proper which begins where assimilation stops.

2d. Muscular irritability. This is found in that vital property of the human body, called contractility. It is the power to respond to a stimulus.

3d. Reproduction. This is the power to separate a part of the corpuscle so as to form a new life.

There are two great centers of the body organism, the brain and the heart. The blood is life; it is bearer of the substances upon which vitality depends. The air is borne in the blood during the vitalizing process and the food substance is carried through the blood in those processes by which it is utilized as a tissue builder. In the bodily organism likewise, the nervous system maintains the control so that by the action and interaction of nerve and cell, the bodily health is sustained, the life is balanced and man becomes the highest of all creatures, a being of intelligence whose brain is the center of his life, from which go forth, impulses that regulate and control as well as direct the physical, mental and moral being.

The question of the division of Physiology is one which has been much discussed. It is based upon function. If we regard function as a means of existence, life itself consisting of the proper exercise of these functions. The old classification of functions was that of (1) vital, (2) animal and (3) natural functions. The best classification is that adopted by Aristotle, according to which they are arranged on

the basis of the object of the function fulfilled. According to Aristotle, there are two modes of existence. 1st. Internal or vegetative and 2d. external or animal, the former including the whole process of nutrition and the latter including locomotion. This idea was fully developed by Grimaud who speaks of the functions as two-fold. 1st. Internal taking place in the interior of the body, the chief function being digestion in connection with nutrition; and 2d. external in relation to external objects, the locomotive power directing all these external movements. One of the most complete divisions is that adopted by Richerand. This division is also based upon an object or end fulfilled. I. Functions in the individual life, (A) those which are subservient to the preservation of the individual by assimilating to his substance the food by which he is nourished. These include digestion, absorption, circulation, respiration, secretion and nutrition proper. (B) functions which tend to the preservation of the individual by establishing relations with external things and beings. This includes the nervous system and the special senses including also locomotion and animal mechanics. II. Functions subservient to the preservation of the species, including reproduction, embryology, changes of life, temperament and death.

The field of nature is divided, first, into inorganic substances ossessing the common property of matter. Second, into organic, or living beings, obeying particular laws while subject to the general laws of the Universe. Each of these orders has two forms. Inorganic is found first in simple elementary substances incapable of analysis, and second: Complex substance capable of analysis and decomposition.

Organic beings exist in the forms of vegetable and animal life. While we differentiate nature in this division we must remember the mutual dependence of these parts which demand simultaneous existance.

Difference between organic and inorganic beings—The latter are found to be very different from those endowed with life. 1st. In the homogeneous nature of their substance. 2d. In the complete independence of their particles, each of which has in its causes to account for its peculiar mode of existence. 3d. In the power of resisting decomposition; and 4th. In the absence of those powers which free organic bodies from the absolute dominion of the physical law. We cannot get a true idea of life without considering those bodies which are endowed with life as compared with those which have no life.

1st. Difference between organized and inorganized bodies is found in the homogenousness of the inorganic and the compound nature of the organic. If we break a block of marble we find no difference among the pieces except in size and shape. If we divide an animal or a vegetable we find different parts all of which have differences among themselves.

2d. Organic beings cannot live or exist in their natural condition unless solids and liquids enter into their composition. In the minerals the water or fluid which enters into or penetrates the substance does not form a part of it, except in so far as they enter into chemical composition.

3d. All the parts of the living body, animal or vegetable, have a natural tendency to a common object, the preservation of the individual and of the species. Each of the organs of the body performs its own function, and yet all the organs concur in the promotion of the same object and in development of the life in general. Life, then, would be the result of a series of concurring and harmonic actions. On the other hand, each part

of the inorganic mass is independent of the other parts to which it is united by the force of affinity of aggregation.

4th, Among the animals and vegetables all the individuals of the same class seem to have been formed after the same model; their difference being slight. The forms of organized life, therefore, are more easily determined. That is, these forms are determined organically.

In minerals, the veins of the substance are never alike. For example: Crystals from similar substances often assume very different shapes.

5th. A powerful internal cause seems to arrange the different parts of animal and vegetable bodies so as to present a surface, more or less rounded. Minerals, on the other hand, often take their shape from external bodies, and when a special cause gives to them a special form, as in crystals, their surface is flat and angular.

6th. The most absolute distinction, that is, between the organized and inorganized, is that which depends upon growth and nourishment. Inorganic bodies grow only accretion, that is, by the accession of new layers to the outer surface, while the organic, by reason of their vital powers, receive into close combination, are penetrated and pervaded by the substance they assimilate. In plants and animals nutrition, used in its general sense, is the effect of the internal mechanism and their growth is development from within. In the minerals, growth is not properly a development, but an accession which goes on successively by the addition of new surface layers.

7th. Organic bodies spring from a germ, which at first was a part of another being from which it detached itself for the sake of its own development and growth. Inorganic bodies have no germ, but are made up of distinct parts brought together in combinations.

8th. Organized bodies alone can die. All these have a duration determined by their own nature, and this duration is not determined as in the case of minerals by bulk and density. If man has not the life of the oak, whose substance exceeds his in density, neither does he equal many of the animals, such as fishes, whose flesh is of an inferior consistency to his own.

DIFFERENCE BETWEEN ANIMAL AND VEGETABLE LIFE.

There are much fewer and less absolute differences between vegetable and animal life. There is, in fact, very little difference between a plant and a zoophyte. There is a much wider distance in their internal economy between man, who stands at the head of the animals, and the polypus, which stands at its lowest line, than there is between the polypus and the plant. There lies between organized bodies and inorganized bodies, a space which cannot be bridged, even by the Philosopher's lithophyte. At one end of the animal chain are found living beings, fixed like the plants on their birth spots, sensitive and contractile, like the plants reproduced from slips, yet we can see differences that are sufficiently marked between the animal and vegetable kingdoms.

1st. Difference: between Vegetable and Animal Kingdoms. Vegetables are more complex than minerals, less complex than animals. The proportions of solids to liquids is greater in vegetables, therefore, after death, they retain their form and size. Solids in man are about 1-6 of the body, and after putrefaction his body remains only a little dust and a slight skeleton, when the ground and air have extracted the liquid from his body. On the other hand, a tree is more than three parts of its substance solid wood. After it has been dead for ages, in buildings and other structures, it preserves its form and size, although by drying, it has lost its weight.

2nd Difference: The constituent principles of vegetables, as they are less in number, are also less diffusible. In fact azote (nitrogen), which is predominant in animal substances, is a gaseous and volatile principle, while carbon, the base of vegetable substance, is fixed and solid. This added to the smaller quantity of liquid, explains the long duration after death of the vegetable substances.

3rd Difference: There is one difference sufficient to distinguish between the animal and vegetable life. The zoophyte, fixed on his rocky habitation, cannot change his position and is confined to partial movements—which are possessed also by certain plants. The result is that the zoophyte has not that sensitive unity so remarkable in animals and in man. The zoophyte, whose name indicates an animal plant, is totally separated from all beings of the vegetable kingdom by the existence of a cavity in which alimentary digestion is carried on as a process of absorption. From this animal up to man nutrition is carried on by two surfaces the internal and external, especially the former; While in the plant nutrition, or rather the absorption of nutritive principles, is only on the external surface. Every animal considered as an abstraction has a nutritive tube, open at the extremities. The existence of a polypus is reduced to an act of nutrition, because its whole substance is used in forming an alimentary tube of which the soft surfaces are used in the absorption of substances brought into it. From the worm up to man the alimentary canal is a long tube, open at the two extremities, at first, in the lower forms only the length of the body, from the mouth to the anus; but, in the higher forms of life, this tube returns upon itself in complex folds between the two extremities. It is in the thickness of the walls of this tube between the mucous membrane that lines it internally and the skin with which the membrane is continuous that all the organs are placed which serve to transmit and modify the fluids, together with the nerves and muscles. In fact all that carries on life—that is the processes of life. As we rise from the white blooded animals to the red and cold blooded, and from these to the warm blooded, and finally to man, we find a gradual multiplication of organs contained within the walls of this canal. If we follow the same course downward—that is from the higher to the lower—we find the structure simplified till we reach the polypus, whose canal is so simple that it can be turned inside out without interfering with the proper discharge of functions. That shows that there is nothing on the internal side of the walls of that canal peculiar to the process of absorption as we find it in animal life. Thus it shows a very simple form of the alimentary canal. Man, therefore, and the whole animal kingdom carry about within them the supply of their subsistence and absorption by an internal surface which is their peculiar characteristic.

The digestive tube, that essential part of every animal, is the part of which the existence and action are the most independent of the concurrence of the other organs and to which the properties of life seem to adhere.

Haller, who has often been spoken of as the father of Physiology, states that in the heart we find irritability under the two-fold relation of lively and lasting, in the highest combination. This means the heart retains life longest. He gave the second place to the intestines, the stomach, the bladder, the uterus and the diaphragm. After this, that is, in the third place, all the muscles under the control of the will.

Richerand and Jurine have shown, however, that the intestines are always the last parts in which traces of life can be discovered. After the heart has ceased to beat and the rest of the body reduced to an inanimate

mass, there are certain undulatory motions in the intestinal canal. If the intestinal tube is the ultimum moriens, that is, the last organ in which life lingers, then it is to it we ought to direct stimulation in cases of asphyxia. This connects the lower to the higher animal forms, for Jurine observed in the pulex monoculus that of all the parts of this little white blooded animal the intestines were the last to die. All animals are united in the possession of this canal, simple or complex.

LIFE.

We shall find life to be composed, at first, of a small number of phenomena as small as the apparatus to which life is entrusted. After extending these, as its organs or instruments are multiplied, and as the organism becomes more complex we reach the higher forms of life. The properties which characterize it at first are obscure, becoming more and more manifest as they increase in number as well as in developement and energy, the field of existence enlarging as we ascend from the lower beings to man—the most perfect being. This perfection simply means that living beings are possessed of more numerous organs, present greater results in life and multiply the acts of existence. In the Universe every being is perfect in itself, because each being is so constructed as perfectly to fulfil its purpose. In the plant which springs up, grows and dies each year we have a being whose existence is limited to the phenomena of nutrition and reproduction; a mechanism which consists of a multitude of vessels, straight or winding, through which, the sap is filtered and other fluids necessary to vegetation in the nutritive process. These fluids ascend generally from the roots, where materials are taken up to the higher parts of the organism, where what is left over from nutrition is evaporated through the leaves and the waste thrown off.

Two properties direct the action of this small number of functions—that is, as we find them in the plants—first a latent and feeble sensibility, by which each vessel is affected by the fluid with which it is brought into contact, and, 2nd. a slight contractility in virtue of which these vessels close, or dilate themselves under the fluid impressions so as to effect transmission and diffusion. The reproductive organs in the plant are characteristic. The male stamina bow themselves over the female pistil, shake over the stigma their fertilizing dust, and then die with the flower which is succeeded by the seed. This plant divided into many parts is reproduced also from slips, which proves this fact that each part is not absolutely dependent on each other part, and that each of the parts contains a set of organs necessary to life, and, therefore, can exist alone. This is due to the simpler organs—that is simpler as compared to the more complex—and to the diffusion of the properties of life in all parts, the phenomena of life being less connected than in the animals, especially in man.

Passing from the plant to the polypus, which forms the lowest link in the animal chain, we find a tube of a soft substance both sensitive and contractile, a life and organization as simple as that of a plant. The vessels which carry the liquid, the vessels called tracheæ, which give access to the air, cannot be distinctly traced in this homogeneous substance. There is no special organ of reproduction. The fluid oozes from the internal surface of the tube, first softens and then digests the aliments, the tube then spontaneously contracts and ejects the waste. The mutual dependence of parts is absolute, for, if it is cut to pieces, each piece becomes a new polypus,

organized and living. These animals (gemmiparous) have the faculties of feeling and self-motion and are also capable of impressions.

Rising to the worms we have no longer animated substances, simply shaped into an alimentary canal; but parcels of muscular fibers, a vessel divided into a series of vesicles, which empty into one another by contractile movements, starting at the head and going to the tail, a spinal marrow composed of ganglia chains—that is different from the ganglia centers—and tracheæ analogous to the plant respiratories, and also in some of them we find gills. These all indicate perfect organization—these are the essential features that we find in this worm class of animals. The worm may also be divided into many pieces, each part becoming a separate organism, but there is a limit to this separation—that is, it is different from the polypus, any part cannot become separate and become a new organism. The crustaceous tribes, among them the lobster, give us a more complex organization in which we find distinct muscles, an articulated skeleton, movable in all its parts, a spinal marrow, a brain and a heart. The last two organs—the brain and the heart—place this form of life above that of the worm, because we find in this class a kind of intelligence and will impulses. These are based on the fact that these animals will follow smell—very distinctly, too, and flee from danger apprehended by the sense of vision.

There are also viscera for alimentary digestion, sensibility and contractility, subject to internal stimulus; Nerves and locomotive muscles which connect with the external world. In these animals there can be no separation of parts with the continuation of life, although a few parts may be cut off and still preserve the central foci of life.

Passing from the white blooded animals to the red and cold blooded such as fishes and reptiles. Life is more involved in organization and reproduction still further limited. Gills in these—in the fishes, of course—and lungs in others are added to the heart. The action of these chief organs, however, is less frequent. The serpent, for example, passes long winters torpid with cold, without air and without life motions. This is due to the capacity to suspend the admission of air and the capacity of breathing at very long intervals. The heart and other vessels of the fish feel and act within him without consciousness. Fish have senses, nerves and a brain, from which it knows what affects it; muscles by which it moves and adapts itself to surrounding environments.

Coming to the red and warm blooded animals, at the head of which we find man. We find this class of animals all alike, except in the less essential organs. All of them have vertebral columns, four limbs, the brain which exactly fills the cavity of the skull, a spinal marrow, nerves of two kinds, five senses, muscles partly voluntary and partly involuntary. Added to these organs a long digestive tube coiled upon itself, furnished at its opening with salival and masticatory instruments, with lymphatic glands, arteries and veins, a heart with two auricles and two ventricles, and lobular lungs. These are all the organs of life, and yet none of these organs live, except while they partake in the general action of the system and are under the influence of the heart. All of them die, or at least vanish from visual observation, when separated from the animal.

The human body consists of a collection of liquids and solids in the proportion of five to one, in six parts. This proportion is maintained throughout. The liquid, which constitutes the greatest weight of the body, existing before solids, for the embryo, which is at first in a gelatinous condition, may be considered a fluid. It is from the liquid that all the organs

receive their nutriment to repair their waste. The solids formed from the liquids return to their former state; after having for a sufficient time formed a part of the animal they become decomposed by the nutritive process. Fluidity is thus essential to living matter, because the solids are uniformly formed from the liquids and eventually return to their former state. Solidity, therefore, is an accidental condition of organized living matter. Water forms a great part of this fluid and is the common vehicle of all the animal fluids. It contains saline substances in solution and even animal matter. We find this animal matter in the muscles in three different forms, gelatin, albumin and fibrin. The first of these substances, the gelatin solidified, forms the basis of all the organs of a white color, such as tendons, aponeuroses and cellular tissue and membranes.

2nd. Albumin exists abundantly in all the humours.

3rd. Fibrin of the blood forms the cement which is employed in repairing the waste of a system of organs,—the muscular system. Animal matter passes successively through these three forms, gelatin, albumin and fibrine, and these three different changes mark the successive changes in animal matter. The solid parts are formed into different systems, to each of which is ascribed a certain function. Limiting the expression organic system to a combination of parts which concur in the same usage as a means of existence or life, there is a difference between life and existence.

We have in all ten special functions—that is in the human body. Now we will mention these ten functions.

1st. The digestive apparatus, consisting of a canal extending from the mouth to the anus.

2d. The absorbent or lymphatic system, which consists of vessels and glands.

3d. The circulatory system, which is a combination of heart, arteries, veins, and capillaries.

4th. Respiratory System.

5th. Secretory or glandular system.

6th. Sensitive system, embracing the brain, the spinal marrow and the organs of sense.

7th. The muscular system, that of motion and locomotion, including muscles, tendons and apeneuroses.

8th. The osseous system, including bones, appendages, cartilages, ligaments, and synovial capsules,

9th. The vocal system.

10th. The sexual system—reproductive system.

Each of these systems contains in its structures several simple tissues. Those of the human subject being cellular tissue, nervous tissue, muscular tissue, besides the horny tissue which constitutes the basis of the epidermis, hair and nails.

These four substances may be considered as real organic elements, because we cannot succeed in converting anyone of these tissues into another. The idea of a simple elementary fiber which Haller, the Father of Physiology, sought in vain to discover, is purely imaginative. Bichat, on the other hand, exaggerated the multiplication of tissues when he concluded that there were twenty-one generating tissues. In the human organization we find the four constituent elements of tissue substance, the epithelial tissue, connective tissue, muscular tissue and nervous tissue. The epithelium is one of the simplest structures of the body. It consists of one or more layers of microscopic nucleated cells, called epithelial cells,

arranged so as to form membranes which line the free surfaces of the interior and exterior of the body, forming the free surfaces of the epidermis and of the mucous and serous membranes. Epithelial cells consist of a very fine cell wall and nucleus and nucleoli, and sometimes, also, other cell contents of liquid or granular matter. There are four varieties of these, that is, the epithelial.

1st. Squamous tesselated epithelial cells, flattish cells which overlie each other, as in the cuticle, and are placed side by side like pavement stones, as in the serous and synovial membranes and in the interior of the lymphatics and blood vessels.

2d. The granular or spheroidal epithelium cells. These are globular or rounded cells which line the interior of the compound glands, like the liver and gastric glands, which do the secretory work of the body.

3d. Ciliated or columnar epithelium cells which consist of conical shaped cells placed side by side, standing on their lower extremities. These cells line the stomach and the intestines. The upper part of the gastric follicles and the gland bladder.

4th. Ciliated epithelium cells which are generally of the cylindrical form, the free extremities of which are ciliated—that is lined with very fine cilia. These cells line the entire free surface of the respiratory tract, including all the air passages and tubes down to the air cells. We find a tesselated variety of the ciliated epithelium cells, which line the ventricles of the brain and the central canal of the spinal cord.

The second form of tissue, connective, cellular or areolar tissue consists of a mesh work, in which quantities of white fibrous tissue intermingle with a small quantity of yellow elastic tissues. This tissue is abundantly distributed throughout the body, forming a kind of a matrix which binds the tissues and the structures and the tissues together. It is very pliant and elastic. The white fibrous tissue consists of parallel bands of wavy fillaments like the fibers of a cord and is very tough, It is found in connective tissues, ligaments, tendons and fibrous membrane like the periosteum.

The yellow fibrous tissue consists of a very fine and well defined elastic fibers about 1 40,000 part of an inch in diameter. This forms the greater part of the elastic tissues, such as the vocal cords, the ligamenta subflava. This connective tissue also includes adipose tissue, which consists of fat cells distributed through the meshes of connective tissues. It also includes cartilages by which the ends of bones forming the movable joints are tipped. and also osseous tissue both in its cancellous form of slender fibers, of minute bars joined together like lattice work, and in its compact form, which consists of concentric rings of bone, arranged around a center, such as we find in the shafts of the long bones.

3d. Form of tissues—muscular tissue, is found in two forms, the smooth and unstriped muscular fiber, which form the chief constituent of the involuntary and hollow muscles as the alimentary canal, bladder, the coats of the arteries, excretory ducts, the great lymphatics and the trachea viris. Its chief characteristic is its power of contractility, under the influence of the will or nervous stimulation or chemical, mechanical and electrical irritation.

2d. Form is the striated muscular fiber which consists of a pale yellowish fiber, each fiber having a sheath and each fiber being capable of division into fibrillae. These fibrillae form bundles, the smaller bundle

being called the fasciculi and the sheath of connective tissues by which they are bound together, is called, fascia.

4th. Kind of tissues, nervous tissues. This comprises two distinct structures, the fibrous and the ganglionic vesicular The first kind forms the essential constituent of nerves and the interior of the brain, the second kind, the different ganglia, the outer layer of the brain and the inner portion of the spinal column.

The vital parts of the human body are composed of these tissues which complexly arranged enter into the organization of the human system. Some of these organs are so essential to life that, with the cessation of their action, life becomes extinct. These vital organs are termed primary organs and regulate the other organs which are called secondary. None of these organs can act unless the heart sends into the brain a certain quantity of blood, vivified by its contact with the atmospheric air in the pulmonary tissue; hence the primary organs are usually spoken of as the heart, brain and lungs. The oxidation of the blood and its distribution into all the organs is, therefore, the chief phenomenon on which the life of man and of the most perfect beings depends. This constitutes the life of man from a Physiological standpoint. That concludes what we have to say about life from the standpoint of Physiology.

SYMPATHY AND HABIT.

All the different parts of the body are bound together by close relations and sustain these relations by means of sensations and affections—affections used here in its Physiological sense. Now these bonds which unite all the organs by establishing perfect harmony among all the actions taking place in the animal economy are called sympathies. The cause of these sympathies we cannot state. We do not know why when one part is irritated another part—although it may be far distant—partakes in the irritation. We cannot tell what are the means of establishing such sympathies, nor can we follow the connection of organ with organ when the affection is mutual. The only thing we know is that the mutual affection or sympathy exists. This sympathy, on account of this mysterious action and influence is all the more important in the animal economy, for such sympathetic relations form one of the most important differences between animals and the unorganized bodies, in which we find no sympathy at all, except so far as it exists in chemical affinity. Nothing in the inorganic world bears any resemblance to this sympathy, unless it be the magnetic or electric fluid. In the animal life, however, the connnctions are apparent and the effect visible, although the cause is secret. The nerves cannot be exclusive media of this sympathy for some muscles which receive branches from the same nerve do not sympathize, and some parts of the body are in close sympathy whose nerves have no connection. Each nervous branch having a connection in the brain and in the part to which it is sent, remaining distinct from those of the same trunk. There are different kinds of sympathy—that is physiologically. We will analyze some of these kinds of sympathy.

1st. Functional sympathy: on the part of two organs discharging the same function or functions. Ex., the kidneys may discharge each others duty. The uterus and the breasts during pregnancy are mutually sympathetic.

2d. Membranous sympathy, which is due to the continuity of the membrane, for example: stone in the bladder associated with an itching in

the glands—the membranes in that case being continuous. Fluid secretion is carried on in this way that is by this membranous sympathy, as when food is in the mouth we find an irritation of the parotid ducts and glands, which tends to increase secretion. These are all exemples of the membranous sympathy.

3d. The irritation of the pituitary gland—which is found, as you know, in the sphenoid bone—results in the contraction of the diaphragm, and, as a physical result sneezing follows. Haller, the great physiologist, ascrided this to reaction. When snuff produces too great an impression on the olfactory nerves the uncomfortable sensation is sent to the brain, which, in turn, determines toward the diaphragm sufficient motion to contract the chest and so expel the air and the substance giving discomfort.

4th. The principle of life seems to nontrol the phenomena of sympathies. Ex., The rectum, when irritated by excrements contracts—the contraction taking place through sympathy. There is an accessory and a simultaneous action of the diaphragm anp the abdominal muscles.

5th. In the symmetrical organs possibly habit may explain sympathy—that is the reason we associated sympathy with habit—because, in this place it is explained by habit. Ex., When the sight is directed toward an object placed laterally the rectus externus of the eye of that side acts at the same time as the rectus internus of the other eye—that sympathy being explained by habit. These examples show us that sympathy exists, but,whether it is due to action, contractility, sensibility or to the vital force we cannot tell. It is by sympathy that all the organs concur to the same end and give each other mutual aid. It also explains how local affections spread and give effect to the whole system. Sympathy is thus both a physiological and pathological condition.

General diseases always originate by associations in the isolated affection of an organ or system. This, of course, is a pathological, rather than a physiological statement. The most complex affections—physiological affections—consist really of only one, or a very small number of elements, all the rest are accessories depending upon sympathy. This is an Osteopathic idea which traces the complexity of affections to a unitary cause in some function, organ or system.

The stomach, when irritated, gives rise to pains in the head and in the limbs, with burning heat and nausea, loss of appetite and anxiety affecting the whole system. The stomach thus oppressed spontaneously contracts to rid itself ~~of itself~~ of its nauseous contents and this produces an universal disturbance in the system, the affected organ calling to its aid all other organs. In this way by organic combinations in the form'of pathological insurrections nature struggles to free itself from its morbid conditions. To assitt nature in this sympathetic action is to act the part of a physiological physician.

Habit consists in the frequent repitition of certain actions or motions, either by the whole body or by a part of it. The greatest effect of habit is to weaken the organic sensibility. For example: To use snuff, at first increases the mucous secretion of the nose, but, if it is used for a certain time, it ceases to have any effect on the pituitary membrane.

We become aware of our existence by means of sensations. All life congists in the action of stimuli on the vital powers. Sentient beings feel the necessity of continued emotions and, all the vital actions bear upon the the production of agreeable sensations.

Pleasure and pain; the extremes of sensation approximate to each other

under the influence of habit, for habitual suffering renders us insensible to pain.

The organs of the body, some of them more than others, are influenced in their actions very powerfully by habit. By some physiologists this idea is carried so far that they regard death as a natural consequence of the law of sensibility. Life, according to this view, consists of the constant excitement of living solids by the fluids of the body, resulting because the sensitive parts after long habituation to this excitement cease to have the capacity of feeling.

We find a marked difference in the physiologica and psychological fields, in regard to habit. The physiological axiom is that habit impairs the sensitive power, whereas the psychological principle is that habit improves the judgement. Physiology says impairs and psychology says improves—so that habit reduces physical sensibility and improves intelligence, giving facility to all the actions under the control of the will. That finishes what we have to sap about habit. We pass on to the

VITAL FORCE.

These words do not represent a being independent of actions, but they represent the sum of those parts which animate living bodies in distinction from inert matter. From a remote antiquity the differences between organized and inorganized bodies have led to the hypothesis of a principle underlying all activity, a force harmonizing all the functions of life and directing them to the preservation of the individual life and species life. This ancient doctrine has passed down to us through the ages almost unchanged—that is the doctrine of a life-principle, subjecting animal life to laws differing from those of inanimate matter, a force that raises them above the mere chemical affinities and a free life-principle pervading the whole system, securing functional harmony and promoting unitary action on the part of the organs—this includes all the organs of the body. All the phenomena which we observe in the living human body are proofs of the existence of this life principle which animates the body and all the functions of the animal kingdom establish it. The multitude of the phenomena in the human life are reduced to a focus by harmonies, mutual connections and reciprocal independence. All the powers which animate the separate organs unite themselves and are combined together in this life-principle. This vital power is in constant conflict with the powers which govern inanimate bodies. The law of individual life is always struggling against universal nature. Life is this struggle determined in favor of the individual and death is this struggle determined against the individual; when the individual falls once more into the lifeless form. This vital force is constantly influencing, modifying and altering the physical laws. Although the principle of life is not seated in any one organ, or part of the living being but animates every organ, yet there are in the living body certain parts which are more alive than others and from which others derive their life and motion. These central foci of vitality gradually diminish in number in the animals as we get farther away from man, so that in the lower animals, life is more generally diffused and less centralized, until we reach in the downward scale complete diffusion of life, and loss of centralization. This course is not only traced down into the animal, but also into the vegetable life.

This vital force is not the soul, for this would bring us into the realm of metaphysics. We can illustrate this point by an example: If a nail is thrust into a sensitive part of the body a sharp pain is felt—that is normal-

ly—the fluids rushing to the injured part which becomes swollen and highly sensitive. All the vital powers in this process are quickly aroused and sensibility becomes more acute; contractility is intensified and there is a rise of temperature.

This does not mean that the soul is awakened, but that the vital powers of the body are aroused, sensibility and irritability. In this way the vital principle which watches over the vital properties and protects its functions comes to the rescue of the injured organ and manifests its existence, first by arousing and then directing the action of the vital powers. Martyn Paine has shown that there is only one vital principle—this in opposition to a great number of writers who preceded him who tried to show that there were a number of vital principles. Organized matter possesses certain inherent properties which manifest the phenomena of life. There are two of these inherent properties: 1st. Susceptibility, or the capacity of receiving impressions, and, 2d., vital affinity which produces atomic changes resulting from received impressions. These constitute the elementary properties of organized and living matter, whether in protoplasm or bioplasm in virtue of which there is a capacity of development. These are the two properties of the vital force.

The human body may be subjected to minute examination after dissection under the microscope. From this examination the matter of the body is found to consist of certain structural substances, which by chemical examination are found to possess certain characteristics, the chief of which is that of potential energy, which can be set free by oxidation or other chemical processes.

The body consists, therefore, of several chemical substances which, on the whole, contain a large amount of potential energy. This is true of the living body; at death the body contains still a large capital stock of energy, but this capital is soon exhausted under the processes which accompany putrefaction. The body, once living, is soon reduced to dust and the stock which was once stored in the body is soon exhausted because there is no repair or replacement.

In the living body we notice certain characteristics. There are six in number and we will name them one by one.

1st. Activity, represented in movements, either of the body upon itself, or of the entire body from place to place, locomotive movement. This activity is essentially internal and represents the energy of the body itself.

2d. External circumstances often determine this activity. Ex.: Bodily sensibility and contact form the two bases of such movements.

3d. There is a continual process of heat generation, and heat giving forth, going on in the body, by which animal heat is produced and preserved in the body, thus giving to the body a normal temperature above its environment and which it imparts to other bodies.

4th. The body is sustained by taking in the food substance similar to the body substance assimilating it to the animal nature and using it as nutriment to supply the body with free energy.

5th. By respiration, the body continually supplies itself with fresh oxygen.

6th. The body gives out, from time to time, waste matter, the result of oxidation of the food substance, or of a part of the body substance. The living body, therefore, is to be distinguished from the dead body in three particulars.

1st. It is constantly losing energy, and as constantly replenishing its stock of energy.

2nd. In the dead body, all the liberated energy passes off in the form of heat: while in the living body, it is set free from the body in mechanical movements, and even while existing in the body, it assumes forms that are different from heat, although, finally changed into heat in some form.

3rd. In the dead body external bodies affect it only in setting free quantities of heat which result in decomposition, while in the living body the liberated energy assumes some form of motion from the most simple movements of the body, or a part of the body, to the most violent and sudden contortions of the bodily system.

The main problem of physiology, therefore, is to explain how the living body can do what the dead body cannot do, namely:

1st. Restore its lost energy through the renewal of its substance and, 2nd., give out from itself, not only a certain amount of free energy but a certain kind of energy determinate and special. The human body from its earliest stages is divided into parts which are different from each other and become more different—the differentiation increases as growth advances. The cells of the body are differentiated in such a way that groups of cells unite together to form certain tissues, the whole body ultimately consisting of masses of such tissues, each tissue having its own structure. Each tissue differs, not only in structure from every other tissue, but ultimately eaeh tissue assumes particular functions, there being an accurate division of labor among these tissues. Aside from this histological structure of tissue, physiology takes account of two divisions of tissue. You remember histology gives us four divisions, physiology reduces these to two.

The Physiological division is based upon function or use.

1st. Those which are employed in restoring lost energy by renewing the substance.

2d. Those which are used in freeing energy to be converted into heat and motion. In the main, nervous tissue is used in the production and distribution of nervous impulses and the muscular tissue in the production and direction of movements, these movements being directed controlled and harmonized with the environments by nervous tissue. In any case, energy is expended, and this energy being converted into heat leaves the body either in the form of heat or mechanical work. This necessitates the replenishing of energy and the renewal of the substance. In order to assist these two main tissues in the processes of renewal and throwing off waste all the organs of the body are brought into service to animalize the food substance, and so prepare it for use by muscular and nervous tissues, and also, to take up and finally eject from the body its waste. From this standpoint we have two other kinds of tissues, physiologically.

1st. Tissues of alimentation which take up and prepare the food, and 2d, tissues of excretion which clear away the waste materials in order that muscular and nervous tissues may have the least trouble in the process of up-building. These tissues are arranged in organs, and these organs represent mechanisms, whose movements are carried on by muscular tissue under the direction of nervous tissue. Thus we have two classes of muscular tissues, the one concerned with external locomotion, and the other with internal organic movements. There are, also, two classes of nervous tissues, the one bearing upon the external movements, and the other upon internal movements. When the food substance is prepared for nutriment, it is carried to the different tissues by means of blood, which, under the

control of the vascular system circulates all through the body carrying nutriment to the various tissues, and also, by the respiratory system, bearing the oxygen supply to its tissues according to their needs—that is the needs of these tissues in the economy of nature. This, in outline, gives us a brief sketch of Physiology as a science, and of the physiological functions, of the light thrown upon the subject by chemistry, biology, anatomy and pathology, of the vital principle which permeates the entire physiological subject and of the complete harmony among the different organs whose functions, though distinct, are part of that unital arrangement by which the human body fulfills its purpose in the preservation and manifestation of the individual life and in the transmission of that life from generation to generation in the life and history of the species.

CHAPTER II. THE BLOOD.

SECTION I. The General Physical and Physiological Properties.

The different tissues of the body are interlaced with a network of fine vessels, the capillaries, to which the blood is carried by the arteries, and from which it is conveyed by the veins. The blood is contained practically within this tubular system and is kept in circulation mainly by the force of the heart's action. This blood is in reality a tissue of the body, and in its circulation is really concerned with the whole field of physiological life and development, carrying the animalized materials to the different tissues; carrying the oxygen absorbed by the lungs also into the tissues; carrying off its waste products, and assisting in the regulation of the animal temperature. Here we are to consider not this physiological action, but the blood as a constituent element of the body. That is, we consider the constitution of the blood rather than its functions. These functions belong to the different fields of physiology that follow in connection with the different organs of the body.

The blood in its liquid form consists of the plasma, also called the liquor sanguinis, an almost colorless fluid in which flow, at least, four different kinds of corpuscles.

The corpuscles are minute bodies, some regular and some irregular, and are known as the red corpuscles, the white corpuscles or leucocytes, the blood plates, plaques or platelets, and 4th, the granules. The blood plasma is colorless when it is free from the corpuscles, or of a faint straw color when it is seen in large quantities. This straw color being due to the presence in the plasma of pigment of a special kind.

The proportion of plasma to corpuscles in size is usually stated about 2 to 1. The blood plasma is the liquid part of the blood before coagulation and differs from the blood serum, which is the liquid part of the blood squeezed out of the blood when it coagulates. The reaction of the blood is alkaline, due to the presence of the alkaline salts in the blood, chiefly the carbonates of soda. In different animals we find this alkalinity varying. Reckoning it as carbonate of sodium, (Na_2CO_3), human blood corresponds to .35 per cent of this salt. This is very important, because during the process of digestion the alkaline reaction is said to be increased while exercise causes a diminution. The specific gravity in the adult male may vary from 1,045 to 1,075, the average being 1,055, whereas, in the female the variation is from 1,041 to 1,070, the average being 1,050. It also varies with age. It is increased by exercise and rises normally during the night, being decreased after meals, during the day and after hemorrhage. The specific gravity of the corpuscles is greater than that of the plasma, hence the cor-

puscles when coagulation is prevented, tend to sink—that is, to sink in the plasma. This specific gravity varies among these corpuscles themselves—the red corpuscles being heaviest and the plaques being lightest. The redness of the blood is due to these corpuscles. The plasma in the living vessels appears to be colorless as does the serum in thin layers—in thick layers the plasma and serum have a slight yellow color due to the presence of pigment. These red corpuscles in man, and in the mammals, except the camels who are of the camelidæ family, are bi-concave discs without nuclei with a diameter of from 7 to 8 micra, (one micron equalling .001 mm) and a thickness of one to two micra. Being discs they are circular when viewed on the flat and rod shaped when viewed on the profile. In number they vary much in health and during sickness, the average being five millions per cubic millimeter in the male and four million five hundred thousand in the female—this number is affected by increase or decrease of the plasma, or by increase or decrease of the the red corpuscles. The number varies with the constitution, nutrition and manner of life, and also with age; they are greatest in the fœtus and new born child. It varies also with altitude—a high altitude increasing the number of corpuscles; a diminished pressure of oxygen in the air increases the production of these corpuscles. The increase or decrease in the number of corpuscles takes place in normal conditions according to the changes in the tissues and by the presence or absence of water in the blood, and also by abnormal conditions relating to the number and size of the corpuscles—these abnormal conditions belong to pathology, not to physiology. The red color of the corpuscles is due to the presence of hæmoglobin, and this may also determine the condition of the blood, whether normal or abnormal. When seen microscopically these corpuscles, taken singly, have a faint red color, yellowized; but when they are seen in masses they are blood red, varying from the scarlet red of arterial blood to the purple red of venous, this variation being due to the amount of oxygen in combination with hæmoglobin. The red corpuscle is elastic as it may be deflected under pressure, resuming its original form after the removal of the pressure. The shape of the red corpuscles, therefore, depends upon physical conditions of the plasma, serum, or the fluid in which they are found for the time. These corpuscles consist of a colorless framework (not compact), which is spoken of as the stroma. This stroma is a differentiated protoplasm consisting of proteid substance and other matter. This stroma is normally associated with hæmoglobin, which may be analyzed into proteid matter of the globulin family, and the coloring pigment of hæmatin. In general the function of the red corpuscles is to carry oxygen from the lungs to the various tissues. This function depends upon the presence of hæmoglobin, which easily combines with oxygen gas. Of the total solid matter of the corpuscle about 95 per cent is hæmoglobin. The combination of the hæmoglobin and stroma is not known, physiologically. In laky blood the corpuscles are broken up and the hæmoglobin is set free passing into the plasma in solution, the redness being diffused in the serum. Normal blood is opaque, due to the reflection of light from the surface of several corpuscles. Laky blood, on the other hand, is transparent because there is no longer the surfaces of the corpuscles to reflect the light. The blood may be made laky either by ether, chloroform or bile, and this is the abnormal condition that we find sometimes in the living bodies as well as by the addition of a large excess of water. Landois, by several experiments, has shown that the serum of one animal's blood may render laky blood of another animal—a condition that is of some import-

ance in the subject of transfusion, an abnormal condition of the blood. This property is called globulicidality, different kinds of serum possessing this property in different degrees. If the blood is diluted with water, the blood becames laky after a certain point is reached. The quantity of water required differing in different animals. In the red corpuscles a certain amount of water is present normally; the amount being determined by the substance—the substance of the corpuscles—and the attraction of surrounding liquids. If this attraction is diminished or destroyed, water passes freely into the corpuscles, and forces out the hæmoglobin. Liquids containing inorganic salts sufficient in quantities to prevent the corpuscles imbibing water are spoken of as isotonics to the corpuscles—that is these salts prevent the corpuscles dissolving and giving up their hæmoglobin. Ex., Sodium Chloride 0.65 per cent solution acts as such an isotonic. There are a number of other isotonics, but this is the one that works the most perfect.

Hæmoglobin is a very complex substance of the compound proteid class. When analyzed it is found to consist of 96 per cent of proteid (globulin) and 4 per cent of pigment (hæmatin). In the absence of oxygen decomposition produces globulin and hæmachromagen (this last is a compound substance), when oxygen is present under oxidation giving place to hæmatin. This compound substance combines readily with oxygen and gives it its absorbent power, giving to the hæmoglobin its physiological property, which is utilized in respiration—that is carrying the air from the lungs to the tissues. Hæmoglobin seems to be different in different animals, theamount varying with the individual and with the condition of life.

In the blood of a man weighing 68 kilograms—that is 150 pounds—there are found about 750 grams—1.65 lbs.—of hæmoglobin distributed among 25 trillions of corpuscles. This vast extent of the hæmoglobin is used for absorbing oxygen in the lungs, the bi-concave form of the corpuscles increasing the surface, which is open to the air's action. Hæmoglobin unites freely with air, forming a chemical compound known as oxy-hæmoglobin. This combination, the oxy-hæmoglobin, is not very stable, so that if the compound is placed where oxygen does not exist it gives off its load of oxygen, a property of the blood which is of great use in respiration. The hæmoglobin unites with carbon monoxide (CO), to form a very stable compound, for this reason, the inhaling of the carbon monoxide gas results generally in death by asphyxia. This carbon monoxide gas, of course, is found in the coal gas. That is one reason why coal gas is so fatal. The same is true of nitric oxide (NO).

Iron is found to be present in the hæmoglobin, varying in different animals; the per cent being from .34 to .48. This iron element is of great value in combining with oxygen. Each atom of iron in the hæmoglobin molecule combining with it one molecule of oxygen. Oxy-hæmoglobin may be found in crystal form, the power of crystallization varying in the blood of different animals. If we take some blood and put it into a test tube, then add a few drops of ether, shake the blood until it becomes laky—you know we said ether and chloroform were substances which produce that condition, shake the blood until it becomes laky, and then put the tube on ice until the crystals deposit. Small portions of this crystal may be examined under the microscope. These crystals assume different forms in different animals. In man and most of the animals they assume the rhombic prism form. Hæmoglobin in solution, examined under the spectroscope, gives characteristic absorption bands.

The red corpuscle is a cell that has lost its nucleus. The corpuscles

therefore, do not live long in circulation—that is in their individual form. The bile pigment discharged from the liver is derived from hæmatin, which is a decomposed product of hæmoglobin. As these pigments are continually excreted the red corpuscles, which supply the hæmoglobin must be constantly destroyed in a normal state of health. It was formerly believed that the spleen, where red corpuscles have been found in various stages of decomposition, that the destruction of these corpuscles takes place in the spleen. Later researches, however, have shown that the blood of the splenic vein contains no hæmoglobin in solution. It is more probable that no special organ or tissue destroys these red corpuscles—that is, it has no special function—but that the process of dissolution goes on in any part of the circulation, the hæmoglobin thus set free going to the liver and being excreted as bile pigment. This constant destruction of red corpuscles demands a constant formation of new ones. In adult life the red marrow of the bones is the great reproducer of the red corpuscles. In the passages of the capillaries and minute veins of the marrow are found nucleated colorless cells, these being transformed into non-nucleated cells, and then passing into the blood as red corpuscles. In the embryonic life this process goes on in other parts of the body, such as the spleen and the liver, as well as in the red marrow of the bones.

The white corpuscles or leucocytes. These are less numerous than the red corpuscles, the variation ranging from one in three hundred to one in seven hundred. Although they are less in number, they seem to be of greater importance in their relation to the blood. At rest they are colorless, irregular, spherical masses, varying in size with an average diameter of ten micra and of a coarse granular form. They often change their form and thus possess amœboid movements. In these movements the spherical form of the corpuscles may be changed to the flat plate form in which it displays a nucleus and sometimes two or more nuclei. These leucocytes are examples of undifferentiated protoplasm. The whole corpuscle contains a large proportion of its substance, water, only ten per cent being solid. This small solid proportion consists chiefly of proteids, for example myosin, similar to, if not the same as muscle myosin, paraglobulin, nuclein, containing a large quantity of phosphorous. In addition to the proteids we find fatty matter, starch and sugar—not in their clear form—together with quantities of potassium and phosphorus. The blood leucocytes are of different kinds, the chief characteristic being the amœboid movements, by which they readily pass about absorbing into their substance fatty or pigmentary substance, wandering about from place to place, and even passing through the vessel walls as in diapedesis. This process takes place to a slight extent normally, but is largely increased by inflammation. Sometimes they are called migratory or wandering cells. Various classifications have been given of these corpuscles. In recent times they are usually spoken of as three in number.

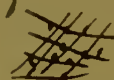
1st. The lymphocytes: small corpuscles with a round vesicular nucleus, incapable of amœboid movements. These resemble the leucocytes. They are found in the lymphatic glands, and, in fact they pass into the blood from the lymphatics, supplying the blood with new white corpuscles.

2nd. Mononuclear leucocytes. These are medium sized corpuscles with a vesicular nucleus, and possessing amœboid movements.

3rd. Poly-nucleated leucocytes. These are large corpuscles with a tripartite nucleus, and they show active amœboid movements. According to some physiologists these different classes of corpuscles represent progress-

Red Blood cells Comparis

1- More numerous
2- Circular, flat - biconcave biconvex Di $\frac{1}{3200}$ i

3- Non-Nucleated
4- Heavier than blood plasma
5- Consists of Stroma or network - in meshes of which we find Hemaglobin No definite cell wall - although frame work more or less compact. 

Origin.
6- 2 fold - White corpuscles, from cells in Spleen and red marrow of bone.

7- Function
Carries O- to tissues
In Capillaries pass quickly along in the middle of Stream of blood. developing as they pass - a force which pulls after them the heavier part of the blood. In Practical Phys- Statical or frictional electric force.

'se.

White B.C.

1 - Less numerous.

2 - Globular, subject to changes in amoeboid movements.

- Nucleated.

. Lighter than blood plasma

- Consists of non-differentiated Bioplasm in connection with which we find the nuclei corposle and sometimes globules of fat. Lives nourishes itself and has powers of complete organism.

. Origin 1st in Spleen
2nd in Lymphatic glands
3rd Red marrow of bones.
4 Areolar tissue.

- Function. Form Red Corpuscles. Migratory cells.
Pass through Capillary walls - by process called Diapedesis - Mass collected in cuticle called abcess. Physiology being attempt of Corpuscle to throw off poison.

produced by friction of corpuscles -

8 - End of Red -
Broken up in Liver and Spleen. forming element at the basis of Granules -

8 - End of White
Some form red corpuscles -
Others escape into tissues chiefly in connection with Lymph -

ive stages of the corpuscular development. The difference in form depending upon the stage of development. Other physiologists regard the corpuscles as all belonging to one family, the difference being due to the taking in of granules or the production within the cell itself of certain granules as products of metabolism. The functions of these corpuscles are numerous. We may classify them under four heads.

1st. They aid in absorption, for example, the absorption of fats and proteids from the intestine. In this case the absorption takes place in the lymphatic tissue of the alimentary canal by the lymphocytes.

2nd. They aid in the process of coagulation.

3d. They help to maintain in normal condition all the blood plasma by supplying it with proteid matter.

4th. They are said to protect the blood from the pathogenic bacteria. It is claimed that these leucocytes either eat up the foreign substance introduced into the blood, hence they are called sometimes phagocytes, or else they form certain substances which destroy these foreign substances. This is the basis of the theory of immunity from infectious disease effected by inoculation, e. g. vaccination.

THE BLOOD PLATES OR PLAQUES.—These are small disc shaped or irregularly rounded bodies, ranging in size from .5 to 5 micra in diameter, but homogeneous in their structure. According to Hayem they were early stages of the developing red corpuscles and he calls them hæmatoblasts; this, however, from later research is erroneous. On removal from circulating blood they rapidly dissolve, and this dissolution for a length of time prevented their microscopic examination. They exist in the blood itself and are not products of coagulation. Lilienfield has shown that they consist of a nucleo-albumin which is found, also, in the nuclei of leucocytes. When these poly-nucleated leucocytes dissolve in the blood, these nuclear fragments exist for a time as plates or plaques. If this statement is true the function of these plates is either to build up the plasma or they form a waste which is thrown off through the plasma from the body, in addition to aiding in the process of coagulation. Gibson calls them colorless microcytes.

The 4th kind of corpuscles; elementary granules: These consist of fatty substance derived from the chyle and small protoplasmic germs produced by the lymphatic glands. They constitute the smallest and undifferentiated elements that are found in the blood.

SECTION 2. Chemical Composition of the Blood.

The blood, including the plasma and the corpuscles, contains a great number of substances, the chief chemical interests of the blood being found in the changes which it undergoes in the several tissues, and as a source of food supply, and also, in carrying off the waste products. The whole blood contains gases in certain proportions, chiefly the three gases; oxygen, carbon dioxide, nitrogen. These gases vary in the different kinds of blood, and especially distinguish arterial blood from venous blood. In a quantity of blood containing a hundred volumes, we find the following proportions in the two kinds of blood:

Arterial blood	O, 20.	CO_2, 40	N, 1 to 2.
Venous blood	O, 8 to 12.	CO_2, 46	N, 1 to 2.

The plasma is resolved by coagulation into serum and fibrin. If the corpuscles retain the proper quantity of water necessary to their integrity, then the blood eonsists of from 1-3 to 1-2 by weight of corpuscles, the rest

plasma. The constituents of blood, chemically analyzed, are found to be as follows: Water; proteids, three kinds of which exist in the plasma; fibrinogen, paraglobulin and serum albumin; combined proteids, hæmoglobin and nucleo-albumin; fats and other extractives, such as sugar, urea, uric acid, etc.; and lastly inorganic salts. The plasma consists of the three proteids fibrinogen, parag lobulin and serum albumin. In one hundred parts of serum we find about 90 parts of water, 1 to 2 parts of fatty substance and other extractives and 8 or 9 parts of the proteids. Fibrinogen: This belongs to the globulin family and is distinguished from paraglobulin by a number of special reactions. Its chief reaction is that under proper conditions it gives rise to an insoluble proteid fibrin which is essential in the blood coagulation. It occurs in small quantities in the blood, varying from .2 per cent. to .4 per cent. Its function in the blood, aside from coagulation, is unknown. Paraglobulin: This, also belongs to the globulin family, exhibiting the general reaction of this class. The amount of it found in different animals varies. In man it is about three per cent. This proteid is valuable as a source of nitrogenous food to the different tissues, but, whether it is used directly by the tissues or by conversion into another proteid is uncertain. Serum albumin: This is a typical proteid showing the general reaction of albumin. In the blood it comprises all the proteids that are not precipitated by the sulphate of magnesium ($Mg\ SO_4$). It is said that heating under proper conditions gives coagulation at three different temperatures, indicating the presence of the three proteids mentioned. The amount varies in different animals; in man being about 4.5 per cent. It is generally believed to arise from the digested products of the food, not being changed during the process of digestion, but during the act of absorption into the blood.

Physiologically this serum albumin is the chief source of proteid nourishment for the tissues of the body, furnishing part of the proteid material made use of in the metabolism of the tissues. The fatty substances, which are scarce, except after meals or under pathological conditions consist of the neutral fats, for example: Stearin, palmatin and olein with a certain quantity of their respective alkalines. Among the extractives we find nearly all the extractives of the body and the food, for example: Sugar urea, kreatin, etc. The chief chemical feature of the saline constitution of the blood—that is the blood plasma—is the predominance of sodium over potassium salts, the abundance of chlorides and the presence of phosphates or their presence in very small quantities. The red blood corpuscles contain about 60 per cent. of water and 40 per cent. of solids.; 39 per cent. of the 40 per cent. being organic, chiefly hæmoglobin, to the extent of 30 per cent., that is the hæmaglobin. We find about 1 per cent. of lecithin and cholesterin. The salts consist chiefly of potassium and .5 of magnesium, calcium and only very small traces of chloride of sodium. The chief acid is phosphoric acid, about .2 per cent. combined with potassium to form the phosphates. In the white corpuscles the chief proteids consist of myosin and paraglobulin. In the nuclei we find nuclein. We also find lecithin and other fats, glycogen, the extractives and the inorganic salts, the potassium salts predominating.

SECTION III. Coagulation of the Blood.

The blood when shed from the living body is perfectly liquid. Soon, however, it becomes coagulated, and this viscidity is one of the most impor-

tant properties of the blood, after it escapes from the body. The process of coagulation is easily followed. The blood when shed from the vessels very soon becomes viscous and then settles into a jelly or gelatinous condition, quickly becomes more firm, thus preserving the mould of the vessel. If the blood is left in this jelly condition however it becomes more compact; it shrinks and yields a quantity of faintly yellow colored fluid which is called the blood serum. This liquid appears first in layers on the top, then around the sides, and last on the bottom surfaces of the compact substance—the gelatinous substance. This jelly substance after shrinking assumes a more solid consistency, forming a clot, or, as it is sometimes called in its Latin form, crassamentum. In the process of clotting the upper surface becomes slightly concave; the clot itself assuming the form of a network of fine fibrils, in the midst of which are found entangled the red and white corpuscles. These fibrils are found to be composed of fibrin, an insoluble proteid not present in the normal blood. This fibrin appears in the fine threads which hold the clot in its gelatinous condition; the corpuscles being held firmly in the filaments of this fibrin. The white corpuscles on account of their capacity for amoeboid movements often pass out into the serum. If the blood is shaken after being drawn the filaments are broken and the serum becomes red instead of pale yellow, due to the presence of the red corpuscles.

If the blood is vigorously whipped with a bundle of rods the fibrin will be deposited on the rods and the liquid then left will consist of serum and blood corpuscles. This whipped blood is called defibrinated blood, resembling ordinary blood with this exception, that it cannot clot again. The Physiological value of coagulation is that it causes haemorrhage to cease by binding up the wounded vessel. The time taken for clotting varies; but, normally in human blood it becomes viscous, that is the first stage, in from two to three minutes, assuming the jelly form, the second stage, in from six to ten minutes. In a few minutes more the first serum drops, representing the third stage, appear, and this goes on gradually, being usually completed in from ten to forty-eight hours.

In the blood of the horse the process of coagulation is slow, allowing the red corpuscles and some of the white to sink to the bottom before viscidity begins so that the upper part of the clot assumes a lighter color, while the lower part of the clot is a dark red color. The upper part of this clot is called the buffy coat, and the clot is said to be buffed. The blood of the pigeon clots almost as soon as it is shed, some say even in the process of shedding; whereas the blood of the chicken may not coagulate for ten or twelve days, retaining its liquid form for that length of time. The clotting may be accelerated by the following circumstances:

1st. By the presence of Oxygen, viz., the free access of the air.

2d. In a temperature a little above that of the blood, for example, hot sponges or fomentations applied to a wound accelerate clotting.

3d. Contact with foreign bodies, or the increase of the extent of the substance with which the blood comes into contact, for example, the extent of the vessel in which the blood is placed. Blood will also coagulate in a vacuum, but this may be prevented by taking precautions to prevent agitation of the blood and by keeping the temperature of the vessel nearly that of the blood vessel from which the blood has been taken. Coagulation is retarded and may even be prevented altogether:

1st. By the absence of Oxygen. This may seem to conflict with the statement we made before in connection with the vacuum. But in the

vacuum we have a peculiar condition depending upon pressere and also the presence or absence of certain gases in the blood which is not a normal condition of the blood as we find it in the vacuum, and this is the reason why in the vacuum we have the tendency to accelerate rather than retard coagulation.

2nd. By a temperature below zero or above 60 degrees centigrade. For example, blood from animals which normally clots slowly may be put into narrow vessels surrounded with ice. In this case coagulation is retarded, the process of coagulation is retarded, and may be even prevented. Blood in this way may be kept for an indefinite time in a fluid condition. The corpuscles sink—that is in this condition when the blood is put in a narrow vessel surrounded by ice—and in this way we get the pure blood plasma.

3d. By the addition of neutral salts, for example, Sulphate of soda, Magnesium sulphate, carbonates of sodium and potassium, the nitrate of potassium, and the alkaline chlorides. In this case the corpuscles settle and we get plasma that is known as salted plasma due to the presence of these neutral salts. The best solution to use when securing this salted plasma is a solution of 27 per cent magnesium sulphate.

4th. By saturation of the blood with carbon dioxide (CO_2). Venous

5th. By certain albumose solutions. Some of the products of proteid digestion, for example, peptones and albumoses. These injected into the blood in the living vessel retard coagulation for a long time—we speak of the living vessel for even in a case of death of the body, the vessel lives after the death of the body for a certain time—that is why we mention the living vessel after death—the death of the body or after its removal from the body.

6th. By the use of an extract from the heads of leeches.

Normally coagulation does not take place while the blood is in circulation through the vessels. It would seem that the living walls of the vessels, the lining membrane of the walls of the vessels prevents this clotting. Many of the conditions that we find in the living body are favorable to coagulation, but in addition to these conditions the blood continues to sustain an intimate relation to the living tissue. For example, if the base of a frog's heart be ligatured while pulsating, the blood remains fluid in the beating heart—that is, the heart of the frog continues for two or three days in this condition—so that the process of ligature is quite easy. But if the heart be punctured, the drop that oozes out from the puncture coagulates almost instantaneously. Lister maintains that coagulation is produced by contact with foreign bodies, and he says that this is the only cause of coagulation. In the case that we mentioned, that is the case of the frog's heart, he says that the blood was kept agitated by the heart's beat. But the blood will continue fluid in an artery between two ligatures for a considerable time, and that, of course, is independent of the beat. Blood coagulates more slowly in a dead vessel—that is a dead vessel that once was alive in the living body—than when shed and placed in an artificial vessel. Coagulation first commences in the heart and the larger vessels, then passes to the intermediate vessels, and last of all to the smallest vessels. In the case of the smallest vessels, decomposition sometimes sets in before coagulation takes place. The cause of coagulation and the theories of explaining it are as yet shrouded in mystery. Two things are to be explained in connection with coagulation.

1st. The formation of fibrin, and second, the question of the derivation of fibrin from the fibrinogen of the plasma. Hewson in 1772 was the first

to state that fibrin was disolved in the blood, and that it coagulated to form a clot. Prof. Buchanan, at one time Prof. of the University of Glasgow in Scotland in 1845 showed that two substances are necessary in order to form fibrin, by proving that certain fluids, for example, Hydrocele fluid, which do not coagulate spontaneously undergo this change, when part of a clot, or fluid from the clot are added to it. He concluded from this that there is a soluble fibrin which, when acted upon by the colorless blood corpuscles —the white corpuscles—produces fibrin.

Schmidt, who has investigated the subject for over thirty years, has given us the most recent theory of coagulation.

At first he discovered fibrinogen (this was away back in the '60s, about 61 or 62,) which he found in the blood plasma and in the lymph, belonging to the globulin family of albuminous bodies, fibrin being formed by a union of fibrinogen with fibrinoplastin or paraglobulin—this last, also, is of the globulin family derived from the blood ~~serum~~. Plasma

Schmidt's latest theory—which we ~~find in~~ connection with his researches of about three years ago, 1894, in regard to coagulation, is that three conditions are necessary to produce coagulation. 1st, certain proteids, the two globulins of the blood. Out of the paraglobulin is formed the fibrinogen, and this fibrinogen is changed into fibrin.

2d. The fibrin ferment is necessary in order to effect these changes. This ferment Schmidt calls thrombin.

3d. A certain quantity of neutral salts is necessary in order to precipitate fibrin in its insoluble form—that is as we find it in the clot. This ferment he formed by adding to the serum of ox blood twenty times its volume of strong alcohol, setting it aside for a month. After the close of the month the coagulated proteids were extracted by means of distilled water, and in this way there was obtained a solution containing small quantities of proteid—a solution which he found to assist, and also to induce coagulation. He did not go so far as to use the word produce, but to induce, to assist and induce coagulation. Schmidt held that this ferment was formed in shed blood by the disintegration of the leucocytes or white corpuscles. At the present time it is believed that there is derived from this disintegration of the leucocytes and also from the disintegration of the microcytes—these are the blood plates called microcytes—a ferment necessary to coagulation. So far as our knowledge extends at the present time, we conclude that the formation of fibrin is due to the action of this fibrin ferment upon fibrinogen and that both of these—both the fibrin and the fibrinogen—originate from the colorless corpuscles—the leucocytes and the microcytes. The blood does not clot within the vessels, normally, except in the case of intra-vascular clotting by the introduction of some foreign substance, which either injures the inner lining of the vessels, or acts as a ferment on the blood. The reason of its not clotting in the vessel is that the nucleo-proteids are not present in the blood in sufficient quantities at any one time to produce coagulation.

In the formation of the fibrin the leucocytes and the microcytes disintegrate in the blood in circulation, but this does not take place to a sufficient extent to form a ferment on account of the defensive activity of the cells lining the interior of the vessels. When this defensive cause is removed in shed blood, these nucleo-proteids combine with salts to form fibrinogen and fibrin with the result of the coagulation of the blood. This point may be accepted as settled in Physiology, viz.: that coagulation is due to the formation of fibrin—the mysterious point, of course, is in connection with

the form of that fibrin—how the formation takes place. We also know that this does not take place in the blood normally, but that it is formed by the union of fibrinogen and paraglobulin, probably under the influence of the fibrin ferment. Fibrinogen exists in the blood plasma and paraglobulin also exists in the blood, principally in the corpuscles—some Physiologists say in the white corpuscles and some say in the red corpuscles. Some Physiologists say that the reason why the blood does not coagulate in the living vessel is that the fibrin and the paraglobulin are both contained in the white corpuscles; that the fibrin ferment is also derived from the white corpuscles, and as long as these white corpuscles remain intact, none of these substances, the fibrinogen, paraglobulin or fibrin, can escape so as to form by union the fibrin. If this disintegration of these white corpuscles takes place, these three substances escape and the result is the fibrin is formed, and, of course, coagulation results. This disintegration of the white corpuscles takes place when the blood is shed from the living vessels, and also when the epithelial lining of the vessel is injured or destroyed. In the former case we have blood coagulation, in the latter case we have intravascular clotting or thrombosis—a condition that is associated with the term that was used by Schmidt to represent the ferment, thrombin. The blood may be regarded as a tissue—like the other tissues of the body—made up of living elements requiring constant assimilation and elimination in order to maintain the normal life conditions. Coagulation, on the other hand, is the result of certain chemical changes concomitant with the death of the blood —that is we do not say the death of the body, or the individual, but the death of the blood, because these are distinct; while it lives—that is while the blood lives—no such changes take place. Constant chemical interchange between the blood and the walls of the vessels—the blood vessels—is required to sustain blood life, also the body life. It is the blood life that we discuss now. The solid formation found in the clot and the separation of a liquid proteid found in the serum is in line with what we find in other tissues of the body, for example, soft, contractile tissue at its death undergoes a change almost identical with coagulation; a condition that we have to deal with when we come to the Physiology of the muscles. The only thing that we know definitely in blood nutrition is this fact that a constant relation is required between the blood and the lining membrane of the vessel wall. Coagulation does not take place when this relation is preserved; but, in the case of a lesion of the delicate membrane—whether the lesion is due to injury or to malnutrition, coagulation follows. During the first stages of inflammation, on account of the arrest of the flow of blood, the small vessels suffer from defective nutrition, allowing certain of the blood elements to escape, while the corpuscles adhere together and the plasma coagulates. We find the same thing in the larger vessels, when an inflammation of the lining membrane of these larger vessels destroys the capacity of keeping up the delicate relation of the blood and the vessel walls. On the valves of the left side of the heart and in the arteries where the delicate relation of blood to the vessel wall is subjected to great strain we often find slight lesions covered with small blood clots. Foreign substances, for example, a thread introduced into the living and circulating human blood, form a clot, the colorless corpuscles collecting on the thread. The time necessary to produce intravascular clotting is long—that is compared with the extravascular, the blood having been stopped for several hours, some Physiologists say for even more than a day, without this coagulation. This is due to the fact that so long as the relation of the blood and vessel walls

is maintained, clotting does not take place. In fact, the tissues die before the blood will clot in the vessels; that is, you have the death of the tissue before you have the death of the blood. Even after death the tissues live and the blood continues fluid as long as the vessel wall can nourish itself and the blood. In cold-blooded animals the tissue lives longer than in the warm-blooded animals; for example, the heart of a tortoise will live under favorable conditions for two or three days after its removal from the body and the blood will still continue in its fluid condition until after the death of the heart, that is, after the death of the heart tissue. Certain chemical changes must go on in the blood to preserve this integrity—the integrity of the blood, the cessation of these changes resulting in new products among which you will find fibrin. When the blood is removed from the vessel wall, or the relation is broken, the production of fibrin results—from one of two causes—either:

1st. Because the blood elements have been destroyed, or

2nd. Because of the impossibility of the reintegration of those blood elements. In either of these cases the fibrin appears as a death element, in the case of intravascular clotting this death element is removed by the vigorous action of the other life elements in the body and in the tissues, while in the case of shed blood these life elements cease to exert an influence and hence complete coagulation results. This finishes the subject of coagulation of the blood.

SECTION 4. Quantity of Blood.

The total quantity of blood in the vascular system gained by balancing the blood supplied by the tissues which give to, and those which take away from the blood is estimated approximately by various physiologists.

The method used by Welcker is called the colorimetric method, which consists in bleeding the animal as thoroughly as possible and weighing the blood thus obtained, afterwards washing out the blood vessels very minutely with distilled water and estimating the amount of hæmoglobin in the blood washings. The result is that, in man 7.7 per cent. of the body weight is found to be blood, or about 1-13 of the body weight; for example, In the case of a man weighing 68 kilograms we find about 5,236 grams of blood in the body—that would bring it to just about 1-13 of the body weight. In the new born child the blood is found to constitute 5.25 per cent. of the body weight—that is 1-19 of the body weight, compared with 1-13 in the adult.

In the rabbit and in the cat—which are so favorable in physiological experiments—the blood has been found to weight 5 per cent. of the body weight—that is 1-20 of the body weight. In the same individual the variation is not very large at any moment, because a sudden drain upon the water of the blood, for example, by profuse perspiration is counteracted by the passage of water from the tissues to the blood, and vice versa—the reverse condition.

Torchanoff, the Russian physiologist, has invented another plan. He subjects the person to a Russian bath in which profuse perspiration takes place. The amount of hæmoglobin in the blood is determined both before and after the bath, and from this he estimates the total volume of blood—in that way you can find the correct amount of blood in the living being without subjecting them to the extortion of blood. The blood is distributed throughout the system as follows: Taking four parts as the basis; one part is found in the heart, the lungs, the large arteries and veins; one part is found

in the liver; one part in the resting or skeletal muscles and one part in the other organs.

SECTION 5. Abnormal Conditions of the Blood.

This subject is sometimes excluded from physiology by physiologists because they say it belongs to pathology, but it is like some other subjects; the subject is excluded from physiology because it belongs to pathology and it is excluded from pathology because it belongs to physiology, and so it falls down between the two. So the best way is to take it up now. Several abnormal conditions of the blood have physiological bearings; for example, in plethora, or polyæmia there is an increase in the entire mass of the blood, uniformly in all the organs. There are several signs of this polyæmic condition; for example, the bluish-red skin, swollen veins, dilated arteries and the hard and full pulse. When accompanied with the brain congestion we find vertigo and congestion of the lungs. This polyæmic condition may be produced artificially by transfusion—that is by the injection of blood of the same species into the living vessels. If the quantity of blood be increased from 80 to 90 per cent. there is no danger to life, because this amount of blood can be accommodated in the distended vessels. But, if the quantity of blood injected reach 150 per cent life is imperiled. The cause of death would be in this case the sudden rupture of some of the vessels which distended to such an extent that it would result in rupture. Transfusion seems to affect the increase of red corpuscles, this being the most noticeable effect for the longest period—that is, there are other effects, but they are slight, as compared with this. Transfusion is a dangerous process; because the new blood introduced is likely to contain fibrin—at least in its germs, and this may result in intravascular clotting. In addition to this the serum of the blood of one animal may act as a destroyer of the blood corpuscles of another animal. In case of the loss of blood the better plan is not to inject blood, but to inject a solution of sodium chloride, because this solution is isotonic to the corpuscles. There are other forms of polyæmia, but most of these are discussed in pathology. The reverse condition is anæmia—the reverse of polyæmia or the reduction of the quantity of blood as a whole. A large quantity of the total blood may be lost by hemorrhage without any fatal results. In animals a loss of two to three per cent of the body weight is not fatal. While in man a loss of 4.5 per cent—tnat is not of the blood, but of the body weight—that is more than one-half of the entire blood, will prove fatal. It is estimated that in man a loss of 3 per cent may be recovered from. An injection of .9 per cent solution of sodium chloride after such severe hemorrhages, have the physiological effect of putting into rapid circulation the diminished number of red corpuscles and thus securing such a circulation as tends to preserve life and to restore its normal conditions. Females seem to bear the loss of blood better than men. This being due physiologically, to the more rapid renewal of blood in connection with menstruation.

Newly born children seem to be seriously affected by a small loss of blood, whereas in the adult life, one half of the blood may be lost before any serious results follow. Stout and aged people bear the loss of blood with less vigor. There seems to be a connection between the fat substances of the body and the fact that explains this—something will be said of this later. The more rapid the loss of blood, the more dangerous it seems to be. If the hemorrhage is not sufficient to cause death, the fluid portion of the blood and the blood salts are restored by absorption from the tissues,

followed by an increased blood pressure, the restoration of albumin and the formation, and increase in the number of red corpuscles. Regeneration—the reintegration of the blood—sets in in a few hours after a slight hemorrhage and in from one to two days after a severe hemorrhage. During the process of regeneration the number of corpuscles in the different stages of their development increases, that is developing corpuscles containing less than a normal amount of haemoglobin. That is the physiological and chemical property of these developing corpuscles.

In the cold blooded animals hemorrhage seems to have much less effect upon the life than in the case of the warm blooded animals; for example, the frog is able to live for a period without blood. Cohnheim washed out all the blood from the vessels of a frog with a solution of .75 per cent. of sodium chloride and filled the vessels—the vessels washed out—with this same solution. The frog continued to live for several days eliminating normally carbon dioxide. This experiment seems to indicate, physiologically, that the carbon dioxide is formed not in the blood, but in the tissues of the body.

In anæmic persons it is found that proteid composition is increased, resulting in an increased excretion of urea, whereas fat decomposition is decreased. This depends upon the diminution of earbon dioxide. One result said to follow from that is the theory that after the anæmic condition it is very easy to put on fat. You will find this principle to be a very old one. Aristotle, one of the old Philosophers, said that to put the cattle in anæmic condition, artificially, that they could be more easily fattened when recovering from this condition. It is not only so in the human, but also in the animal life. Among the abnormal conditions of the blood we find the presence of animal and vegetable parasites, most important, giving rise to abnormal conditions, which are discussed fully in Pathology. Some of these, especially the vegetable organisms have the power of multiplying very rapidly in the blood, and, as we have seen Physiologically, the blood may be rendered immune against these bacteria. That finishes the abnormal conditions of the blood.

SECTION VI. Variations in the Composition of the Blood Normally.

The blood is influenced by a great number of conditions including diet, age, temperament and sex. The dietary conditions will be referred to later in connection with the food.

AGE:—The fetal blood is very rich in solid matter, chiefly the red corpuscles. This does not say in what stage of development or growth these corpuscles are. This condition gradually diminishes until the close of the intra-uterine life. The amount of solid matter continues to diminish during the progress of childhood; increases during the adult life, and then again diminishes during old age.

TEMPERMENT:—In persons of a plethoric temperment—or sometimes called the sanguineous temperament— the amount of solid matter in the blood seems to be much larger, particularly in the red corpuscles.

SEX:—The blood of the male differs from that of the female, chiefly in a higher specific gravity of the male, on account of the fact that the male blood contains a larger number of red corpuscles; in the female it also varies in menstruation and during pregnancy, slightly increasing in the former condition and diminishing in the latter. In the latter condition, the specific gravity of the blood is much lower than in the normal female blood.

In the case of bleeding, the specific gravity of the blood—that is in hemorrhage that we spoke of before—is diminished, so much so that the flowing current of the blood from a wound diminishes as the flow takes place. This is due to the absorption of liquid from the tissues of the body. Physiologically this is connected with the conditions of thirst that usually follow the loss of blood. Water is absorbed in the tissues, and hence, gives the desire for water—thirsty condition. The composition of the blood varies in different parts of the body, arterial blood differing from venous blood, and venous blood differing according to the veins in which that blood flows. There are three special differences between arterial and venous blood.

1st. In the arterial blood we have a bright scarlet color, due to the presence of oxy-hæmoglobin, whereas in the venous blood, we find a dark purplish color, due to the deoxidation of the oxy-hæmoglobin.

2d. Arterial blood contains less carbon dioxide and more oxygen than the venous blood.

3d. Arterial blood coagulates more rapidly than venous blood.

In the venous blood there are said to be four different standards of blood.

1st. The normal venous blood. The other three are variations from this.

2d. Splenic venous blood—that is the blood, of course, in the splenic vein. This blood is generally deficient in the red corpuscles, containing a large amount of proteid matter and yielding a fibrin in case of coagulation above the average blood fibrin. There is also a large proportion of the colorless corpuscles and the plasma is deeply colored on account of the dissolved hæmatin. On account of the deficiency of red corpuscles, solid matter seems to be greatly diminished.

3d. Portal venous blood: The blood that is carried in the portal vein to the liver, coming from the gastric and mesenteric veins which contain the dissolved food elements absorbed during digestion from the stomach and the intestines, and also from the splenic vein; this portal blood combines the qualities of these two—that is, you have the characteristic of the splenic blood and also of the blood coming from the gastric and mesenteric veins. The blood carried in the gastric and mesenteric veins varies according to the digestive conditions—both of the food and of the organs of digestion. This blood seems to be deficient in solid materials chiefly in the red corpuscles. On account of the quantity of water absorbed it contains—that is Portal blood—a large proportion of proteids and gives a much less characteristic fibrin than the ordinary blood.

4th. Hepatic Venous blood. This is found to contain a smaller proportion of water, salts and proteid matter than the portal blood. At the same time it contains a much larger proportion of the extractives. Grape sugar for example, This grape sugar being found as a constant element, sometimes called the characteristic element of Hepatic blood. All of these variations in the standard of blood are Physiologically of great value in connection with the alimentary functions. They are mentioned here to bring them into the subject of blood, because we treat here of the general conditions of the blood.

SECTION VII. The Lymph and the Blood Glands.

It is a matter of discussion with Physiologists whether this subject should be discussed under the subject of the blood, or later. It seems to come in quite naturally here, because of the relations between Lymph and Blood. There is no other place where it could come, except in the discussion of the different functions of the body, unless it is to come in connection with the glands.

Lymph is a colorless fluid, resembling the blood plasma, and is found outside the capillary walls, filling the extravascular spaces of the body. All the tissue elements and the outside of the capillaries are said to be bathed in lymph. The entire body, except the epidermis and the epidermal structures, is supplied with blood vessels. The blood plasma filters through the capillary walls, together with white corpuscles and in some cases the red corpuscles. These pass into the lymph and bring to the tissues of the body nutriment and oxygen and carry off the waste. This lymph fills the extravascular spaces which open into the lymphatic vessels, which unite to form larger trunks, forming thus two main trunks: the thoracic or left lymphatic duct and the smaller or the right lymphatic duct. In this way a double interchange takes place from the blood to the tissues and from the tissues to the blood, the lymph acting as a middle man. When this is accomplished—that is this double interchange—a third stream from the lymph to the large lymph vessels carries away from the tissues such parts of the material coming from the blood vessels as the tissues do not, or cannot keep, and also such parts of the waste products from the tissues as are not taken up by the blood vessels. In this way the changes in the blood and in the tissues take place through the medium of the lymph, making it, therefore, most important in connection with the blood. Lymph is essentially the same as the blood plasma, containing the three blood proteids, the extractives, and also the salts. The proteids, particularly fibrinogen, are less in amounts in the lymph than in the blood. This lymph consists of a colorless fluid, containing leucocytes and small bodies of fatty substance, which are very numerous after meals. Formerly lymph was supposed to be derived from the blood plasma by a process of filtration through the capillary walls. In recent times this process of filtration through the capillary walls has been shown to be insufficient to account for the contents and the composition of the lymph. There are two physiological opinions on this subject.

1st. Those who explain the composition of the lymph as due to filtration—filtration through the capillary walls—and diffusion from the blood plasma.

2nd. Those who think that in addition to these two processes—filtration and diffusion—it is necessary to assume a secretory action on the part of the cells composing the structure of the capillary walls. So that, according to this, there are three fluid processes—the filtration and diffusion and the secretion—which would represent the metabolism of the lymph. At the present time it is impossible to say anything more on the subject than simply to quote these points as there are no characteristic points on either side to show that the one opinion is more physiologically correct than the other. Indications seem to point in the direction of the second opinion so far as we have reached—that is the process of filtration through the capillary walls and diffusion from the blood plasma and also the secretion in connection with the cells that are found in the walls of the capillaries. Blood takes in new supplies from the alimentary canal and the lymphatics. From the first it receives directly through the blood vessels or indirectly through the chyle, by the first of course, we mean the alimentary canal; from the second—that is the lymphatics, it receives the lymph—the characteristic lymph. Respiration gives a fresh supply of oxygen. And finally certain elements come to the blood from different parts of the body. These parts of the body that furnish these supplies being sometimes called the blood glands. This is not a very suitable expression because most recent investigations have shown that these ductless glands are not blood glands at all. Although it is not scientifically correct, it is better to adhere to it because they are so-called in all Physiologies.

These are six in number, (1) the lymphatic glands; (2) the glands of Peyer; (3) the Thymus gland; (4) the spleen; (5) the Thyroid body and (6) the supra-enal capsules. The lymphatic and the Peyer's glands, will be discussed later in connection with circulation and alimentation. All these glands resemble erch other in structure, being rich in protoplasm and adenoid tissue, and having many lymph corpuscles. They are also very vascular and they have no ducts, being what are called the ductless glands; they have been called blood glands; because they are supposed to be connected with the formation of blood. The whole lymphatic system is concerned in some way in blood formation. The lymph corpuscles are supplied by the lymph and the chyle. These are chiefly from the adenoid tissue of the lymphatic glands, being washed out by the lymph into the larger lymphatics, the chyle washing out the lymph corpuscles in the adenoid tissue of the villi. In this way the lymph corpuscles are constantly flowing into the blood and these are identified with the colorless corpuscles of the blood. These colorless corpuscles accumulate in the blood and in some way are connected with the formation of the red corpuscles. These colored corpuscles which exist in large numbers, in some way become disintegrated, this disintegration taking place in connection with the liver and the spleen. Phosphate of iron found in the bile is derived from the haemoglobin of the blood. In the spleen, also, large numbers of red corpuscles decompose the large protoplasmic cells inclosing the corpuscles and causing their descomposition. In order to supply the blood with fresh material, the process of blood formation goes on as a counteracting influence to decomposition.

The question as to the origin of the colorless corpuscles is one that has been greatly discussed in the field of physiology.

These colorless cells are the haematoblasts which are found in the spleen and especially in the red marrow of the bones. As found in these, the spleen and the red marrow of the bones, they are found to be colorless, granular, contractile bodies, very much like the leucocytes. The nucleus becomes a large corpuscle, the original blood plasmic cell is sometimes spoken of as the cell of Neumann. Later the nucleus is expelled from the large corpuscle and the rest of the cell that is outside the neucleus becomes filled with haemoglobin and forms the red corpuscles. In Mammals the red corpuscle is not therefore a modified nucleus, but it is a part of the substance of the Neumann's corpuscle outside of the nucleus. The original cell, as we said, was this Neumann corpuscle, the separation of this nucleus in the mammalian corpuscle from the rest of the substances of the corpuscle leads to the formation of the red corpuscle; the balance of that substance being connected in some way with what we find in the red corpuscle.

1st. The colorless corpuscles originate rapidly by the division of the lymphatic corpuscles in the lymphatic glands and also in the Peyer's glands. In the spleen, also, the process of cell multiplication goes on rapidly, the delicate andenoid tissue of this organ being full of pale corpuscles, and the splenic vein being filled with blood that is rich in the white cells. The red bone marrow is the seat of the most rapid formation of the colorless corpuscles. It contains —that is the red bone marrow—fibrillar connective tissue. fat cells, leucocytes and great cells. We find these sometimes spoken of in physiology as giant cells. These giant cells are large cells of irregular shape consisting of protoplasm and nuclei. In the red marrow we find the haematoblasts—that is the cells of the protoplasm, yellow in color. These form the red blood corpuscles. These large nucleated cells are found very abundantly in early embryonic life. Up to the fourth week of that embryonic life, only such nucleated cells are found, that is, no other cells are found in the human em-

bryo up to the fourth week. After this the nucleus becomes smaller, and, in a short time the nucleus entirely disappears, and the corpuscle assumes its bi-concave form. The nucleated forms being found very rarely at the close of the uterine life. After birth the red corpuscles are formed from these nucleated colorless cells, especially in the red marrow of the bones. In the uterine and early extra-uterine life the thymus, thyroid body and the supra-renal capsules are supposed to have blood forming functions; while later in life it is probable that their chief function is to use up and divide into simpler bodies the elements of the blood—that is, to prepare for the blood and to form the elements of the blood itself. As these bodies are ductless glands, those new matters cannot be secreted, and, hence they pass by a reabsorption into the blood again for still further use. These bodies, the thymus, the thyroid and the supra-renal capsules have the function of disintegration, but differentiate with the action of these glands of the blood that unite and back up the process of reintegration into the blood once more.

2d. The spleen is undoubtedly a blood gland, whatever other functions it may discharge. The spleen pulp consists of a mesh-work of delicate fibers of adenoid tissue which hold in the meshes of this pulp, the lymph corpuscles, and also the free or liberated red corpuscles. The spleen seems to discharge a double function. (1) That of forming corpuscles, and (2) of destroying the colored corpuscles. The spleen is also the seat of other operations, such as the decomposition of albuminous compounds and also of acid formations. That is still in line you will notice with the functions of the spleen as a destroyer or decomposer. The spleen, however, can be dispensed with entirely. It has been removed from the body and this removal has taken place without any great disadvantage to the vital system. There is a slight disadvantage, of course, temporarily, but when the local temporary disturbance is removed there is no permanent disadvantage following. In this case of the removal of the spleen it has been found that the lymphatic glands and the red marrow of the bones become more abundant with the colorless cells, and hence more active in the formation of the blood corpuscles. The lymphatic glands by some kind of functional sympathy discharge the spleen function as well as their own function.

3d. In the last stages of the uterine life and the first stages of the extra-uterine life the active growth of the tissues takes place and a large supply of blood corpuscles is necessary. In order to assist this active development of tissues and of blood corpuscles, the thymus gland seems to assist the red marrow of the bones, the lymphatics, and the spleen in the formation of red corpuscles. Later in life after this rapid development ceases the thymus gland becomes absorbed, and, in the case of man finally disappears when manhood is reached.

4th. The thyroid gland. In the early uterine life this thyroid has a duct which opens into the foramen caecum of the tongue, but this duct, like the thymus gland, disappears. Each lobe shows closed sacs which are lined by layers of epithelial cells; these cells being filled with fluid and also the leucocytes and the red corpuscles, partly disintegrated and also partly decolorized—deprived of color. This thyroid gland, if it is greatly enlarged, gives rise to abnormal conditions, two in number, Goitre and cretinism, the latter of which is associated with a form of idiocy. Some say the removal of this gland results in mental weakening—that is, it produces an artificial cretinism. After its removal certain changes have been observed bearing upon the gland function; for example, the red corpuscles are found to be diminished in number and the white corpuscles increase in number. The salivary glands enlarge and

the parotid gland which is normally serous, begins to secrete mucin this mucin being found even in the blood. This furnishes the only evidence that we have that the thyroid is a blood forming body.

5th. The supra-renal bodies. These bodies are found to be large in the uterine life, at the end of the third month of the uterine life being as large as the kidneys. The medullary part which at first is outside of the cortical part —these represent two parts of the supra-renal bodies in the fetal life—afterwards is enclosed by it, containing albuminous bodies and pigment. A watery mixture of these supra-renal bodies gives coloring matter such as we find in the blood. McMunn, a physiologist who investigated this subject, has observed that the spectrum of the supra-renal bodies gives bands of reduced haematin, hence, he claims that their function is to pick out of the circulation worn out coloring matter with their proteids and to separate them so as to prepare them for integration in the formation of new coloring matter. An abnormal condition associated with these bodies is spoken of as Addison's disease, which is the result of these bodies not discharging their proper functions. This disease consists of the sallow or bronzed tinting of the skin, accompanied by giddiness —in its physiological sense—vomiting and breathlessness.

6th. The pituitary body or hypophysis cerebri, although not a blood forming gland, must be classed with these other glands on account of its supposed function of aiding the blood supply to the brain. The supply of new material furnished to the blood may be summarized as follows: (1) By vascular absorption through the alimentary canal; for example, water, sugar, peptones and salts. (2) Lacteal absorption, also through the alimentary canal; for example, water, salts and fats. (3) Through the skin; for example, water anb certain volatile and soluble matters. (4) Through the mucous membrane of the lungs; for example, oxygen, aqueous vapors and volatile matters. (5) Through the lymph or the closed sacs into which the fluid matters have been effused. (6) The lymphatic glands, the mesenteric glands and the other dlood glands; certain protoplasmic elements and lymph cells in which certain exchanges take place between the lymph and the blood; for example, the colored corpuscles of the blood are formed from these lymph elements, or protoplasmic cells. That finishes the subject of the blood.

CHAPTER III. CIRCULATION OF THE BLOOD.

SECTION I. General Statement.

By the circulation of the blood is meant that the fluid during life is contained with ina continuous system of elastic and contractile vessels, that this fluid moves along this continuous course, always returning upon itself in the course of its flow, and that this blood, whatever may be its constitution, moves along in a certain definite direction, never in the opposite direction.

Harvey, the discoverer of the blood circulation, says, that a perpetual movement of the blood in a circle is caused bv the heart beat. The discovery of the blood, by Harvey, dates from 1616. This continuous system consists of the heart which is at the commencement of the arteries and at the termination of the veins; the arteries terminating in capillaries out of which arise the veins. The heart is a double organ, each half consisting of an auricle and a ventricle, the right half containing the blood as it is returned from the body to be passed on to the lungs, and the left half containing the blood passed from the lungs to be sent out into the body. The circulation of the blood is said to be two fold; 1st. Pulmonary circulation from the right side of the heart by the pulmonary artery to the lungs, through the lung capillaries and back again to the left

side of the heart by the pulmonary veins. 2d. Systemic circulation from the left side of the heart through the aorta and the arteries to the tissues by the capillaries, and thence into the veins and back again to the right side of the heart. The circulation of the blood can be followed from the right auricle to the the right ventricle, through the right auriculo-ventricular opening protected by the tricuspid valve. From the right ventricle through the polmonary artery, through the lung capillaries into the polmonary veins which give it passage into the left auricle. From the left auricle to the left ventricle through the left auriculo-ventricular opening protected by the mitral valve; from the left ventricle into the larger arteries, the intermediate arteries and the arterioles into the tissues and the different organ capillaries. From these minute capillaries, the blood passes through the veins, which, at first are small, gradually increasing into larger trunks till it reaches the superior and inferior venae cavae, these constituting the openings into the right auricle. These vessels have walls, all of which are more or less elastic and on being filled with the blood they are subject to distension. This distended condition gives rise to the tension which may be varied at any point by the application of pressure.

This pressure applied at any one point produces a movement of the liquid in the direction of the lesser pressure, and as these vessels represent a closed tubular system, the liquid under such pressure circulates the valvular mechanism being utilized in order to determine the direction of the blood flow. In the living body the contraction of the muscular walls of the right ventricle narrows its cavity and forces the blood out from the right to the left side of the heart through the pulmonary capillaries which are in immediate contact with the respiratories of the lungs. The contraction of the muscular walls of the left ventricle also narrows its cavity, forcing the blood from the left to the right side of the heart, through the systemic capillaries of the body. These two contractions are simultaneous. Each contraction furnishes a force which is utilized as energy being supplemented to a slight extent by the energy which arises from aspiration and also from the contraction of the skeletal muscles. This force drives the blood into the arterial system increasing the arterial pressure, the arteries in turn driving a part of the blood into the capillaries which convey the blood to the veins, tending to equalize the pressure between the arteries and the veins. The pressure never becomes equalized, because if the pressure should become equalized the blood would be evenly balanced between the arteries and the veins. Equilibrium would result in the stopping of the circulation. As the veins empty back the blood into the heart the heart once more contracts and drives more blood into the arteries, thus increasing the arterial pressure and preventing at any one time an equilibration of pressure between the venous and the arterial circulation. If equilibrium were produced in the blood it would remain stagnant, as a certain amount of the blood in the arteries and in the veins in the venous system there cannot be any force of movement to cause them to circulate because the pressure would not be greater in the arterial system, the blood would not be pressed forward, and hence we would not have circulation. In this way we have, 1st the circulation itself, determined and definite, and 2d, the direction of the circulation is also definite and it is always determined toward the lesser pressure. The blood which is the internal medium on which the tissues live, thus circulates through the entire system, mainly through the capillaries whose fine walls are so delicate that certain elements from the circulating blood pass through the capillaries to the tissues outside, while certain elements of the tissues pass through the walls into the blood, thus keeping up a constant interchange of elements between the blood and the tissues by the medium of the lymph. This constant inter-

change accounts for the fact. that there is scarely ever, if any, appreciable change in the volume of blood. There is as much absorption one way as the other and the difference of the volume of absorption would cause an abnormal condition, and so we have in the venous circulation, no difference in the volume of the blood, from what we find in the arterial circulation. If there is a difference it is very slight. The vascular mechanism is so designed that the blood must pass through the minute vessels where the chief work of the blood is done—that is in the capillaries, in such a way as to secure the efficient interchange of these elements. From this general statement we find that the circulation consists of four distinct elements. (1) The heart, whose chief function is to drive the blood into the arteries, through the arteries into the capillaries and thence through the veins into the heart. We speak of this first function, because there are other functions, of course, which the heart discharges. This is the chief one, of course, in connection with the circulation. (2). The arteries, whose chief function is to convey the blood from the heart to the capillaries. (3) The veins, whose chief function is to convey the blood from the capillaries to the heart. (4) The capillaries, including the minute arteries, ending in the capillaries and the minute veins, beginning in the capillaries, whose chief function is to perform the double interchange we have just spoken of, between the tissues and the blood, and the bloodand the tissues.

To understand the circulation is to follow out the blood in its course along this blood path noticing the phenomena manifested at each point and the influences bearing upon the circulation at any one point and on the circulation in general. For convenience the circulation of the blood may be divided into three parts. 1st. The heart as the center of the vascular mechanism. 2d. The blood vessels, and 3d the general circulation, its mechanism and action, including the blood and lymph. Some Physiologists discuss first the capillary circulation because the all important phenomena in connection with blood and tissue interchange are found there. It is better however in systematically discussing the circulation to commence at the great force which represents the center of the circulatory system.

SECTION 2. General Physiology of the Heart.

I, THE HEART AS THE CENTER OF THE VASCULAR MECHANISM.

The heart is a hollow muscle, covered on the external surface with a serous membrane, the pericardium, and on the interior is lined also with a serous membrane, the endocardium, continuous with the lining of the blood vessels. The heart is thus enclosed in a membranous sac and lies behind the sternum and costal cartilages, the base rising upward, falling backward to the right and reaching from the fifth to the eighth dorsal vertebra. The apex reaches downward and forward to the left and its beat is felt in the living subject in the interspace between the fifth and sixth ribs slightly below and to the central side of the nipple. Thus the heart lies obliquely in the chest cavity projecting into the left of the cavity.

The heart is composed of a special tissue together with connective tissue, vessels, that is, blood vessels, lymphatics, nerves and ganglia. The cardiac fibers are intermediate, both in structure and in function, between the nonstriated and the striated fibers. The muscular mass of the heart is called myocardium. A considerable mass of fibrous tissue and fibro-cartilage is seen at the base of the heart between the openings of the aorta and the two auriculo-ventricular orifices from which pass different processes forming the basis of those tendonous rings at the auriculo-ventricular and the arterial openings. To these bands or rings are attached the muscular fibers laid out in layers. In

the embryonic life the heart is tubular in shape, or form, its fibers being arranged in an external circular and an internal longitudinal form. As the heart develops during the embryonic life the longitudinal form becomes curved, the venous portion being doubled over upon the arterial portion, the auricle being in a dorsal position to the left of the ventricle. Later in its development the single cavity of the auricle and the ventricle, such as we find in the embryonic life, becomes divided into two, when the septum is formed, dividing the original single chamber into two. In the case of the auricle, the fibers remain less complicated than those of the ventricle, the fibers of the ventricles being arranged in a spiral form. The fibres of the auricle are perfectly distinct from those of the ventricles, being separated by tendinous rings, these fibers forming two layers; an inner longitudinal set for each auricle and an outer transverse set for both auricles. There are said to be seven layers of fibers constituting the walls of each ventricle, three external layers, three internal layers and a middle layer. These layers are so arranged that the first external layer is continuous with the last internal layer, the second external with the second last layer of the internal, etc. The pericardium is a conical shaped sac; its base resting on the diaphragm and its upper part encompassing the roots of the larger vessels. There is an outer layer of tissue and an inner layer of serous membrane which covers the outer surface of the heart. In the interspace between these two layers is found the pericardial fluid. The endo-cardium or the lining membrane of the heart consists of connective tissue and elastic fibers forming a strong wall which round about the openings into the vessels is very strongly developed. Among the elastic fibers are found scattered bundles of unstriped muscular fibers. The fibers of this muscle being used as a means of resistance to the heart contraction and also a resistance against the extreme pressure on the endocardium. Functionally, the heart is a muscular and a valvular pump working on mechanical principles, the force being supplied by the contraction of the muscular fibers, the beats, or strokes of the heart being repeated so many times per minute—72 normally in man, which corresponds to the pulse. The heart is so furnished with valves that at each beat of the heart a quantity of blood is forced from the left ventricle into the aorta and the blood carries with it a certain amount of force sufficient to drive it along the vessels, the same quantity of blood being received at each heart beat from the veins into the right auricle. The action of the heart is thus partly mechanical and partly vital. The vital action is determined by the causes which produce the rhythm, power or force, and general character of the beat, whereas, the mechanical action is determined by the frequency, force and general character of the heart beat together with the amount of blood that is forced out at each beat. The contraction of the auricles is quite independent of the contraction of the ventricles and the heart rhythm—that is, the frequency of the heart beat—being normal the auricular and ventricular contractions correspond with each other. The character of each beat is determined by the changes which take place in the tissues of the heart. When the heart grows feeble, or when the heart is dying the auricle beats several times to every beat of the ventricle till at last only auricular contraction is found taking place, the right auricle being the last portion of the heart to die, hence called the ultimum moriens. The contraction of the circular fibers around the openings of the veins into the heart, causes the blood to pass into the auricles and the constriction of these fibers prevents regurgitation of the blood, these constricted fibers acting the part of valves. The double layers of fibers in the auricles upon contraction produce a uniform diminution of the cavity of the auricles. The spiral form of the fibers—you remember that was mentioned in connection with the ventricle walls—

in the walls of the ventricles upon contraction give to it great force, so that the blood can be driven out with great force. The valvular arrangement is of great value, physiologically, in connection with the action of the heart. The tricuspid valve protects the right auriculo-ventricular opening. The tricuspid valve consists of three flaps, hence, the name, tricuspid valve, of fibrous and elastic tissue covered on the inside with endo-cardium—the same as in the lining of the heart. These surround the opening and are kept in place by the chordæ tendineæ. The bicuspid or mitral valve protects the left auriculo ventricular opening and consists as its name indicates of two sections or segments of a pointed character and of the same composition as the tricuspid flaps. In the auriculo-ventricular valves we find the striated muscular fibers, the fibers extending from the auricles to the sections or segments of the valves. In this way the valves become shorter at the base and so a larger orifice is presented for the passage of the blood into the ventricles—these minute details being functionally of great importance At the base of these segments or cusps there is a layer of concentrated fibers which act with a constrictive force towards the base of the valves. The aortic and pulmonary orifices are protected by the sigmoid or semilunar valves. Each of these valves consists of three semilunar segments and each segment or cusp is bound by its external surface to the arterial wall, its free surface or margin reaching, projecting inside the vessel These segments consist of fibrous tissue covered with the endo-cardium—the same as the membranous lining of the heart. Opposite each semi lunar cusp is a thickening of the vessel called the sinus of Valsalva—this is a very important function in connection with the circulation of the blood. These sinuses in the aorta are arranged one of them anteriorly and two of them posteriorly.

From the anterior rises the right coronary artery and from the left posterior the left coronary artery, the vessels which furnish blood supplies to the heart substance—that is these arteries supply the blood to the heart substance. It is probable that during the contraction of the ventricle the semilunar valves do not cover the openings of the coronary artery. According to Sandborg these semilunar valves close just after the ventricles have begun to relax. The vessels of the myocardium are very numerous representing the great activity of the heart substance.

Some physiologists have ligatured the coronary arteries in dogs and found that in two minutes cardiac contractions give place to twitchings of the muscle fibers and then the heart ceased beating Ligature of the one artery affects first the ventricle, then the other ventricle and finally the auricles.

In the case of hardening of the coronary arteries found in old age, there is diminished action with heart weakness. This hardening is sometimes called ossification of the heart and induces if it does not produce death finally, from the cessation of the heart simply due to old age. Death may occur suddenly from quick cessation of the heart's action. The size of the heart is roughly estimated according to Lænnec to be about equal to the closed hand. In the child, until the body reaches 40 kilograms, in weight the heart is about 5 grams to one kilogram. When the body weight is from 50 to 90 kilograms the proportion is 4 grams to one kilogram, and when the body weight is 100 kilograms the proportion is 3.5 grams to one kilogram. The proportional heart weight to body weight according to this would be 1 to 150 or 1 to 170, varying with the advance of age, as the auricles increase in strength. The mean weight of the heart in the adult male is from 309 to 312 grams. In the female 255 to 274—smaller in size, physiologically, at least, the average about 270. The two ventricles seem to be about equal in their capacity, although after death the post mortem heart practically seems to indicate that the right ventricle is larger than the left ventricle, but this is due to the fact that the left ventricle is usually empty of blood, while the right ventricle is filled with blood. The wall of the left ventricle is much greater in thickness than the wall of the right ventricle. The thickness of the left ventricle at this middle portion is about 11.25 to 11.40 millimeters; in the female it is slightly smaller, 11.15. In the case of the right ventricle the average thickness in the male 3.8 to 4.1 and in the female 3.6. These represent the physical properties connected with the heart.

SECTION III.—The Physiology of the Heart's Action.

If the hand is placed on the chest between the 5th and 6th ribs below and internal to the central part of the left nipple an impulse is felt. The method of examining the heart in this way is called palpation. If the ear is placed over the heart or in connection with the stethoscope certain sounds are heard, the frequency and the character of which are of great physiolgical value. This method of examination is called auscultation. By means of percussion the exact extent, size and condition of the heart may be ascertained as well as its relation to the lungs and the presence or the absence of the fluids in the pericandium. This method is called the method of percussion. Certain instruments are also used for the purpose of registering the action of the heart. The movements of the heart are found to consist of a series of contractions occurring successively with a certain rhythm. The state of contraction is called systole while the condition of relaxation is called diastole. The two auricles contract and relax simultaneously, followed by simultaneous contractions and relaxation of the ventricles. This gives us a systole and diastole of both the auricles and the ventricles.

As we have seen the heart is a double organ with an auricle and a ventricle in each lateral half. In each part the contraction and relaxation of the auricle is followed by the successive contraction and relaxation of the ventricle. Following this succession of contractions and relaxations there is said to be in diastole—not a part of the heart, but the whole heart is said to be in diastole. In this way we have three periods, the systolic; the diastolic; the diastole of the whole heart. This series of actions beginning with the auricular systole and closing with the diastole of the whole heart is called the period of revolution or the cardiac cycle. The auricular systole occupies 1-5 of the entire period of revolution. One-fifth would correspond with the systole, the ventricular systole, 2-5 of the entire period of revolution followed by the period of rest, which

occupies the balance of the 5·5, which would be 2·5. These correspond with the three periods of the cardiac cycle. The auricular systole immediately precedes the ventricular systole and the commencement of the ventricular systole is simultaneous with the beginning of the auricular diastole. The auricles and the ventricles being thus in diastole 2·5 of the whole period of revolution Chauveau and Marey, two physiologists who have investigated this subject, have made use of the cardiac sound in connection with the tracing of the movements of the heart of a horse—not a human heart in this case. This cardiac sound is very much like the surgeon's sound which is used in connection with stone in the bladder.

This sound is passed into the right side of the heart through the jugular vein and the superior vena cava—the horse is supposed to be still living—the lower end of the sound with its elastic bag being passed down into the ventricle while the upper end of the sound, also with an elastic bag, remains in the auricle. Each bag is placed in connection with a recording instrument—in this case it was tambour of Marey—and along with the cardiograph which is applied externally over the apex of the beating heart, they are attached to a revolving cylinder. blackened, of course, the varations found in connection with the elastic bag being regarded as a tracing on the black cylinder. In this case there are three tracings present, the one representing the lower elastic bag, one the upper elastic bag, and then the one that represents the cardiograph from the apex of the heart. As a result of this experiment the following points have been noted physiologically.

1st. Ventricular contraction is more sudden than auricular contraction. The tracing gives us a ventricular set of curves and an auricular.

2nd. The ventricular contraction lasts longer than the auricular contraction.

3d. Auricular contraction and relaxation occupies almost equal periods, whereas, ventricular relaxation is almost twice the length of ventricular contraction.

4th. As a result of what is contained in the third point, auricular movements are found to be uniform and present a wave like appearance, whereas, the ventricular are irregular and sporadic.

5th. Auricular movement precedes the ventricular and the impulse of the apex against the chest wall occurs during the ventricular movement.

6th. Auricular contraction influences the pressure in the ventricle.

7th. During the ventricular contraction there are oscillations of pressure. influencing both the auricle and the ventricle—there are no oscillations in the auricular contraction, but there are in the ventricular and those oscillations are so large that they influence not only the ventricle but also the auricle. These points present the main features in connection with the changes that are found in the cardiac cycle. Although these experiments were made on the horse, the investigation in connection with the same subject indicates that there is no marked difference from this in the human subject. But these results are as we find them in the horse.

When the auricles pass into perfect diastole, the blood is pouring through the vena cava and the pulmonary veins into the auricles. The auricular cavity being enlarged while auriculo ventricular valve protects the orifices. This distended condition of the auricles is due in part at least to the pressure of the superior and inferior vena cava and also of the pulmonary veins, this pressure being greater than the internal auricular pressure. It is also due in part to the suction action of inspiration drawing the blood from the veins out side of the chest to those inside of the chest and thus promoting circulation towards the

heart—not into the heart but in the direction of the heart. While this takes place the two ventricles are being filled with blood through the auriculo ventricular openings. As soon as the auricles are completely distended, which takes place before the ventricles are distended because the ventricular capacity is greater than the auricular capacity, the auricular systole then begins by the contraction of the auricular walls and the emptying of its cavity—auricular cavity—and by the contraction of the circular fibers of the orifices of the venous openings into the auricles. These movements rapidly pass over the auricular walls, transmitting the wave of contraction on toward the auriculo ventricular orifices. This wave of contraction running along the auricular wall drives the blood in the direction of least resistance—that is of course, out of the auricle into the ventricle the ventricle being partially filled with blood already and gradually passing out of the state of relaxation.

The blood cannot pass backwards on account of the venous pressure and the contraction of the orifices of the veins which marks the commencement of the auricular systole. There is, however, a temporary arrest of the blood flow into the large veins. This indicates that the auricles not only act as a medium for the transmission of blood from the veins to the auricles but also that these auricles act as rythmic cavities which preserve the pressure in the veins, lessening by their distension the pressure in the veins, which tends to increase during the ventricular systole, and increasing the pressure by contraction when venous pressure tends to diminish towards the close of the ventricular diastole.

In the case of the auricles and the ventricles we find during their disastole a suction action which is feeble, however, as compared with the force of pressure. Immediately following the auricular contraction is the ventricular systole, the quantity of blood driven by the auricular systole into the ventricles which have alreadybeen partially filled during the auricular diastole, being sufficient to fill the cavities of the ventricles. While the blood is flowing out of the auricles into the ventricles, the auriculo-ventricular valves become slightly horizontal, this being partly due to the contraction of the longitudinal fibers extending from the auricle into the segments of the valves. On the contraction of the walls of the ventricles the surfaces of the auriculo-ventricular valves come together thus preventing the cusps from being injected into the auricle. The papillary muscles (musculi papillares) contracting simultaneously and tightening the chordæ tendineæ which are attached to the ventricular side of the valves. The cusps are closely pressed together along their margins on account of the fact that the chordæ tendineæ of one papillary muscle passes to the adjacent edges of the two flaps. By this means the tricuspid valve on the right side and the mitral valve on the left side are kept closely and firmly closed, the blood being prevented from regurgitating because the orifices are completely and securely closed. When the ventricular systole begins, the semilunar valves of the pulmonary artery are closed, but as the pressure of the ventricle upon the blood increases, the semilunar valves are forced open and the blood passes into the pulmonary artery from the right and into the aorta from the left ventricle. In the ventricles the pressure is highest at the commencement of the contraction when the pressure is said to be positive. During contraction it reaches its lowest point, becoming negative at the close of the contraction of the systole. At this time there is a suction action due to the emptying of the cavity by the sudden and forceful expulsion of the blood into the aorta and the pulmonary artery. The pressure is negative, also, during the diastole that immediately follows. When the blood pasess from the ventricles, the semilunar valves are forced open, their cusps being stretched across the sinuses of Valsalva, that lie behind each cusp without

being pressed against the vessel wall, the reflux current of the blood preventing the contact of the cusps with the vessel wall, and as the amount of bloodls, greatly increased on account of the blood that is expelled from the ventrice is and the blood present in the vessels before the expulsion, the pressure is increased in the vessels and the vessel walls become distended. When the last of the volume of the blood leaves the ventricles a negative pressure appears behind the blood current, resulting in a reflux current from the artery to the ventricle. This reflux current assists, according to some Physiologists, causes the closure of the valves behind the blood. The ventricular systole now closes after the ventricle has continued in the state of contraction for a short period, the muscular walls relax, the ventricle returns to its original form and position. With the beginning of the relaxation of the ventricles, the auriculo ventricular openings again open and the blood passes from the auricles into the ventricles; at the same time the delicate arterial walls yield to recoil forcing a part of the blood back towards the ventricular cavities in which the blood pressure is much less than the arterial pressure, as they pass into diastole. This quantity of blood that it forced back by reflux pressure finds a lodgment in the sinuses of valsalva, and the pouches of the semilunar valves, closing the valves themselves, thus preventing, in this way, the flow of blood backward into the ventricles. From the close of the ventricular contraction until the auricles are again filled with blood all the heart cavities are dilated, the cavities, themselves, being gradually filled with blood This is the period of rest or pause during which the whole heart is supposed to be resting.

SECTION IV.—Changes in the Heart.

The changes in the active beating heart are so rapid that they cannot be observed so as to form any adequate conception of the exact nature of these changes. The ventricles are constantly changing in their form. For example: While the blood is pouring into their cavities from the auricles through the auriculo-ventricular openings during the increase of the pressure on the walls: while the wave of pressure contraction is passing along the walls; while that pressure is acting upon the blood contained within these cavities in driving it out into the arteries; and finally during the relaxation of the walls after the expulsion of the blood.

During systole the ventricles become tense, being larger during diastole, the difference in size being measured by the volume of blood that is driven out. The whole contents are driven out at each stroke, the emptying taking place from the apex of the cavity towards the opening of the artery. While this takes place there is a change from the hemispherical form with an elliptical base to a more conical form with a circular base, the transverse diameter being diminished and the antero posterior diameter increased. This increased fronto-posterior diameter and decreased transverse diameter changes the form of the base of the ventricle. During diastole the base is elliptical with the long axis from side to side, frontally being convex and posteriorly flattened. During the systole the base becomes circular, the whole base being contracted and thus rendering more efficient the action of the tricuspid and the mitral valves. Ludwig and Hesse, two Physiologists, have made experiments in this connection on the heart of the dog. They distended the living heart of the dog until it dilated under a pressure equal to the arterial pressure. The ventricles are in the diastole and the auricles continue to beat. A plaster cast is made of the ventricles in this state, giving a mold of the diastolic condition of the heart. In order to obtain the systolic phase of the heart, a living heart emptied of its blood is suddenly plunged into a hot solution of potassic bichromate, the solu-

tion is at temperature 50 degrees C., when the heart gives a strong final contraction remaining permanently in this rigor condition, under the influence of coagulation. In this state a cast is made which represents the systole phase. In order to obtain the heart cavities, two hearts were taken, filled with blood; the one filled with blood is put into a cold solution of patassic bichromate, causing the hardening in diastole, while the other, filled with blood is put into a hot solution of potassic bichromate. Casts were then made of the cavities of the heart. As a result of this experiment, it was found: 1st. In diastole, the ventricle is hemispheroidal, the apex circular, the posterior surface flatter than anterior surface; the base an ellipse, its greatest diameter being from right to left, and its shortest diameter from apex to base. The heart assuming an inclination towards the apex. 2nd. During the systole the apex becomes pointed; the ventricle assuming a conical shape, the base is circular, and its transverse diameter is diminished so that from apex to base is longer than the diameter at the base. The inclination of the heart has entirely dissappeared, the apex being now almost exactly opposite the center of the base. The heart is thus decreased in all its diameters except one, this is its perpendicular,—not included at any angle. The arterial openings are scarcely affected if affected at all. The auriculo ventricular orifices, however, are diminished. In this way the fibers of the heart, during the systole, contract at these orifices, assisting the closure of these valves and preventing the regurgitation of the blood.

These changes in form involve necessarily changes in position. During systole the ventricles are inclined toward the head and the median line, while the base of the ventricles recedes from the back, moving toward the apex. This base movement is followed by a lengthening of the aorta, the pulmonary artery causing in all probabilily the descent of the base in the contracting ventricles. The apex remains still in contact with the chest wall. During diastole the ventricle becomes soft and distended, the changes taking place being exactly the reverse of those taking place during systole which I have just mentioned. Cardiac impulse: If a hand is placed on the chest a shock or impulse may be felt along with each beat. In a human subject this impulse is felt in the fifth left intercostal space about two inches below the nipple and about one inch to the left of the sternum. This impulse is synchronous with the systole of the ventricle and is produced by the apex of the ventricle being firmly pressed against the the walls of the chest from which it is separated during the period of rest by the free surface of the lungs. This impulse is a distinct result of the hardening of the ventricle during the systoles the impulse itself being the result of the apex brought out into sudden contact with the chest wall, the impulse being conveyed through the chest wall to the surface of the skin. During systole the apex is brought into close contact with the chest wall by the movement of the ventricle toward the front, on account of which it becomes hard and tense. The ventricles, during systole, contract; the contraction of the cavities producing a pressure that is greater than the aortic and the pulmonary arterial pressure. As a result of this, the ventricle hardens, sudden pressure being assisted by close proximity to the chest wall, imparting a shock to the chest wall and also to the diaphragm. By the use of the cardiograph, this impulse may be traced. If the cardiograph is placed over the spot where the impulse is strongest the lever of the cardiograph rises during the ventricular systole and falls when it passes off. If the lever button is placed slightly away from the point of the strongest impulse, the lever will fall instead of rise during the ventricular systole, because away from the point of impact or strongest impulse the ventricle instead of coming into

close contact with, retires from the chest wall and pericardial attachments of the mediastinum draws the chest wall after it.

In the space which becomes protruded by the impulse, the soft parts are found to be slightly drawn in, this attraction, caused by the lessened size of the contracting ventricles, being called the negative pressure. During the ventricular systole, the heart-form changes. During rest the heart is an oblique cone with an elliptical base, during systole it becomes regularly conical and the base becomes circular. During contraction the apex inclines upward and forward, being driven into the intercostal space, the ventricles turning on the long axis from left to right partially exposing the left ventricle. This twisting motion gives the impulse which is produced by the contraction of the obliquely placed fibers of the ventricles drawing up the apex, this movement being assisted by the spiral form of the aortic and the pulmonary arteries. It has been stated by some Physiologists that the impulse is partly due to the reaction of the ventricles, producing a recoil when the cavities are emptied of blood so that the apex is pushed outward and downward. Other Physiologists ascribe the impulse in part to the elongation of the aorta and pulmonary artery on account of which the apex is pushed outward and downward toward the chest wall. These actions may assist in producing the impulse, but the main cause is the twitching movement of the ventricles. That this twitching movement is the cause of the impulse is evident, (1st), from the fact that the impulse takes place, even when the heart cavity is empty of blood; as, for example, in case of severe hemorrhage. Even in this case—of severe hemorrhage—the ventricle seems to harden and this hardening changes the direction of the heart, turning it around and producing a twitching against the cavity of the chest wall. (2d). This is still more evident from the fact that an empty heart entirely removed from the body and placed upon a table or some flat surface raises its apex as it hardens in the systole, the same impulse being felt in the case of the heart under these conditions if the finger is placed over the rising apex, proving the fact that it is a change in the heart itself—not the question of the presence of the blood and not the question of recoil, but simply the twitching movement of the heart itself.

In order to produce the tracing of the apex beat, or a cardiogram—(the instrument is the cardiograph and the tracing on the instrument is the cardiogram,) various instruments called cardiographs have been invented. The improved cardiograph of Marey consists essentially of a tambour with a button attachment to the membrane, which is applied over the apex beat. The motions of the air inside the capsule—in this case it is air motion—are communicated by means of a tube to a recording tambour. The tracings which are obtained give distinctly the contraction of the auricles contracting in the direction of the axis of the heart from the right upwards toward the left downwards and causing the apex of the heart to move slightly towards the intercostal space. Smaller contractions give slight curve elevations. These smaller contractions being due to the contraction which takes place at the ends of the veins and the auricular appendages. Then follows the curve representing the greatest impulse which is cau ed by the contraction of the ventricles. This contraction being simultaneous with the first sound—these sounds will be discussed in connection with the cardiac sounds. The curve then rapidly falls when the ventricles relax, the blood in the aorta and the pulmonary artery being driven back by the recoil of the arterial walls, thus closing the semilunar valves. This impulse is communicated to the apex of the ventricles causing oscillation of the intercostal space. It would seem from the tracing of the curves that the aortic and pulmonary valves do not close simultaneously—the aortic valve closing first and then

about 1-100 of a second later the pulmonary valve. This difference is due to the greater aortic pressure—the aortic is greater than the pulmonary pressure and in this case the aortic closes sooner than the pulmonary valve. The tracings as found by Landois and Marey by his improved cardiograph seems to come very much like that; that is, the tracing which represents the normal movements or movements in connection with the condition of elements in the cardiac cycle.

The heart seems to exist chiefly for the purpose of exerting a pressure upon the blood in its cavities so as to secure the normal circulation. It is difficult to state these movements because the mercurial manometer fails us in this case. The most convenient instrument to use is a long tube open at the top end and filled with a solution of sodium carbonate. This tube may be introduced through the jugular vein into the right auricle and the right ventricle, and it may be introduced through the carotid artery and the aorta into the left ventricle. By establishing a connection between this tube and the mercurial manometer, in this case it is the maximum and minimum instrument, records may be taken of the pressure of these three cavities; the right auricle, the left ventricle and the right ventricle. In this case we get the maximum and minimum pressure attained in each one of these cavities. As a result of this it is found that the maximum pressure in the left ventricle is greater than the normal pressure in the aorta, that the maximum in the left ventricle is also greater than the maximum pressure in the right ventricle and in the right auricle the pressure is greatly diminished. In connection with the minimum records it is found that there is a negative pressure, that is, a pressure less than the atmosphere. This negative pressure may be partly due to aspiration in the respiratory processes but even when we take account respiration it is found that there exists still a negative pressure, at least, a negative pressure in the left ventricle which is very distinctly marked. This means that at some point in the cardiac cycle there must be a negative pressure normally. This negative pressure may arise in one of two ways—

1st. When the blood is driven out very quickly from the ventricle into the aorta a negative pressure seems to arise. This pressure partially accounts for the closure of the semilunar valves and therefore, this negative pressure would be greatest at the orifices of these valves. The manometer however indicates that the reverse of this is true in the case of abnormal negative pressure, that the greatest negative pressure seems to exist within the cavity of the ventricle itself. For this reason this could not satisfactorily account for the negative pressure, therefore, we have the second explanation.

2. This negative pressure arises, in all probability from the rapidity of the ventricular process of relaxation, representing the rapid return of the ventricle from its contracted to its normal condition. This will also account for the greater negative pressure that is found in the left ventricle because the thickness of the wall of the left ventricle is much greater than that of the right ventricle, and therefore the rapid contraction of the left ventricle will produce normally a greater negative pressure. This negative pressure assists the circulation of the blood by setting up a suction action which directs the blood that has been collected in the auricle into the ventricle, using up almost instantly the negative pressure and preventing it from exercising any disadvantageous influence upon the circulation. The only effect of this negative pressure is to lower, and practically to exhaust the negative pressure in the auricles without extending backward to the veins. In regard to the cardiac pressure in the ventricles we may conclude, therefore, that there are four different phases.

1. The rapid growth of pressure in the ventricles greatly increases until it becomes greater than the aortic pressure when the aortic valves are thrown open.

2. Following this the blood escapes into the aorta while the contraction of the ventricular walls still continues.

3. This continued contraction of the ventricular walls secures the complete emptying the cavities of the auricles.

4. The sudden relaxation of the ventricular wall, during which there is set up the negative pressure, this negative pressure establishing the connection between the ventricle and the auricle by which the blood is induced to pass from the auricle to the ventricle.

Duration of the Cardiac Movements.

The whole cardiac movement is termed a cardiac cycle and consists of three phases, the systole of the auricles, the systole of the ventricles and the pause or diastole of auricles and ventricles, which consists of thediastole of the ventricles, including the period between the cessation of contraction and the commencement of contraction again; and of the diastole of the whole heart, including the period from the end of the ventricular relaxation to the beginning of auricular contraction, during which the walls are neither contracting nor relaxing, the cavities being passively filled with blood. By using the instrument (cardiograph) in connection with the kymograph, the velocity of the surface on which the tracings are made can be estimated and thus approximation made to the time occupied by the cardiac movements. It is found that the systole of the auricles is very short, whereas that of the ventricles is much longer, occupying a considerable part of the cycle period and the diastole of the whole heart varies considerably, in slowly beating hearts being longer and in quick beating hearts shorter. From this we would conclude that the faster the heart beats, the briefer the diastole, and also the briefer the ventricular systole. The chief data used is that in connection with the first and second sounds. This period has been found to vary from .225 to .346 of a second, the variation being small, indicating that the variation takes place—in the pauses rather than in the actual beats. The first sound takes place along with the ventricular systole, and the second sound which marks the close of the ventricular systole. Thus the period between the commencement of the first sound and the second sound represents the ventricular systole. During this ventricular systole there takes place the increase of pressure, the expulsion of the blood and the contraction continued so as to empty the cavity. The cardiac pulsations in the adult male vary from 65 to 75 per minute, in the new born child about 140. There is some relation between the quantity of blood in the circulation and the frequency of the pulsation. Thus as the pulsation becomes more frequent the quantity of blood which passes through the heart per minute increases. In the normal adult male the pulsation will be 72 in the morning, from 70 to 68 in the forenoon, 80 to 84 after meals, and 69 to 70 toward evening, the number of pulsations being fewer during sleep

Taking 72 as the normal heart beat, each period of revolution would occupy about .8 of a second. .3 of a second would represent the ventricular systole, the remaining .5 of a second would represent the ventricular diastole, during the latter part of which takes place the auricular systole representiag about .1 of a second, the .4 of a second representing the period during which neither auricle nor ventricle are contracting. One of the most important questions is the work done by the heart representing the quantity of blood ejected from the ventricles during each systole. It is estimated that 188 grams of

blood (a little over 6 ozs.) is driven out of the left ventricle into the aorta during each systole. Various methods have been used to discover this. The most simple is to remove the ventricle, fill it with blood, equal to the amount of blood calculated from the average pressure of the ventricle. This would give the quantity ejected, as the whole contents are driven out at each systole. Each ventricle gives out the same quantity at each beat, otherwise the blood would be crowded into the pulmonary or into the systemic circulation unequally. Some think this is not the case as the pressure is much greater in the left ventricle than in the right. This, however, is due not to the amount of blood but to the greater peripheral resistance to be overcome in the systemic circulation as compared with the pulmonary circulation. Taking 188 grams as the quantity ejected at each beat at the aortic pressure, which is estimated as 250 mm. of mercury, i. e. 3.2 metres of blood. This means that at each systole the ventricle does 601 gramme-metres of work every beat Taking the heart pulsation at 72 per minute we would have 42.272 kilogram metres for the left ventricle per minute or 60,872 kilogram-metres per day. The right ventricle would be about 2·5 of this amount or 24,349 kilogram-metres, the whole work of the heart in a day amounting to 85,221 kilog. metres or about 1-75 of 1 horse power, equal to the combustion of nearly 30 grams of carbon. If 188 grams of blood leave the ventricle at each beat a quantity equivalent to the whole volume of blood (about 5760 grams in a man of 75 kilograms) would pass through the heart every 30 beats, or once every 25 seconds.

These phenomena of the heart are more or less obvious upon observation. Beneath these are certain molecular changes on which depends the rhythm of the heart and by which many, if not all, of the vital activities are to be explained. One question arises as to the nature of the contraction. Is it a simple contraction, or is it a tetantic contraction? In other words is it due to the single stimulus or the application of a number of stimuli rapidly applied in close succession.

Many of the phenomena of cardiac contraction seem almost identical with those of a skeletal muscle. . Exhaustion decreases the amount and increases the duration of the contraction. In cardiac contraction the period of latent stimulation is much longer than that of the skeletal muscle (proportion 1-3—1-100 of a second.) The length of cardiac contraction is greater than that of muscular tetantic contraction. The electric phenomena of cardiac contraction resembles a simple contraction, e. g. there is negative variation in connection with the heart and by the use of the rheoscope (for testing the electric current) the heart manifests a simple twitching. In the muscle when tested by electricity each contraction is preceded by a short period of lessened excitability representing molecular changes preceding contraction. This is known as the negative variation. By cutting off the ventricle slightly above the auriculo ventricular groove, Muller found that placing the base and the apex on the two galvanometer cushions—there was a negative variation in the heart. Later investigations proved that this negative variation took place in connection with the systole, the negative wave being transmitted at the rate of 20 mm per second. If the heart be rendered motionless by separating the auricles of the sinus venosus, either by ligature or by an incision, it has been found that the variation goes through two stages: (1) the initial stage, stage following immediately the excitation when the portion excited becomes negative to the other parts: (2) the terminal stage coincident with ventricular relaxation, the reverse of that manifested at the beginning at the ventricular systole. There is thus a two fold negative variation manifested in the systole of an excised heart, the 1st at the apex and the 2nd at the base. The period of excitation does not

correspond with the period of latent stimulation but coincides with the period from the beginning of the initial stage to the beginning of the terminal stage. The total period of the initial stage has been found to average about .12 of a second. The application of heat to the apex was found to have no effect upon the initial stage but to increase the terminal stage. The rate of transmission of the stage of excitation was found to be about 125mm per second. From this it is concluded that if the ventricle is stimulated, it becomes at once negative to all the other parts, the wave of stimulation being transmitted in all directions at the rate of 125mm per second. Immediately after this stimulation wave passes there follows a contraction of the fibres, giving rise to a wave of contraction passing over the heart. This wave of contraction in the mammalian heart is found to begin at the apex.

What is called a cardiac contraction commences near the orifices of the larger veins in the right and left auricles. In the case of a heart that contracts slowly, the wave of contraction originates at the orifices of the veins, enters the veins and passes along a short distance, then passes over the auricles and the ventricles. The question that arises here is, whether the cardiac movements are dependent upon molecular changes in the muscular tissue or in the nerve tissue, or in both It is a known fact that rhythmic movements take place in tissues that are not nervous, e. g., the beating organs of many invertebrates, the embryonic heart, the unstriped muscles of the ureter. In these cases there is a compound structure of muscle and nerve. Both muscular and nervous tissues, under definitite conditions, give rhythmic movements. It is, however, believed by many that the rhythm of muscular tissue takes its rise from the impulse of nervous tissue Several experimenters have found that the rhythm of the ventricles is altogether independent of the rhythm of the auricles, the ventricular rhythm being found in the apex where no nerve cells are found. This, however, while purely myogenic, is localized and may be overcome by the general rhythm of the heart as a whole. While connected the ventricular and auricular beat maintain almost uniform properties, whereas on the disconnection of auricle and ventricle, the auricle which keeps up the normal beat, beats faster than the ventricle. It is generally conceded that the rhythm of the auricle originates in the veins which transmit the rhythmic motion by muscular conductivity to the auricles. As the ventricles are structurally distinct from the auricles it is difficult to see how the muscular conduction can account for the propagation of the rhythm from the auricles to the ventricles. Hence, some Physiologists accept what seems the only alternative, that the contraction is transmitted from auricles to ventricles by nervous tissue. This, however, seems quite difficult to understand. These impulses could not be transmitted from auricle to ventricle so as to secure exact succession of ventricular beat after auricular beat without taking for granted the existence of nerve ganglia for the purpose of storing energy to be used at intervals in the ventricular movements. The connection of veins and auricles and the elasticity and rhythmic character of the auricular wall seems sufficient to account for the auricular transmission aside from the necessity of nerve centers.

Gaskell, by experiments on the apex of a frog's heart, which contains no ganglia, has shown that, (1) the involuntary apex beats depend upon the pressure in the cavity and not upon the blood supply ; (2) that by the addition of a weak alkali to the blood supply of the apex relaxation gives place to contraction and a weak lactic acid solution reduces the apex to a perfect diastole, Muscarin producing almost the same result. Gaskell draws some interesting conclusions from these experiments. (1) Independent rhythmic contraction is lessened as we pass from the sinus to the ventricle, the power of such rhyth-

mical contraction varying inversely with the distance of the part from the sinus. (2.) An excised part of the apex can be made to beat artificially at the same rate as the sinus and auricle by the action of nutriment. (3.) A wave of contraction transmitted by the auricle produces ventricular contraction, after passing the auriculo ventricular groove. (4.) By dividing the auricle so as to leave one part in connection with the sinus and the other in connection with the ventricle, a contraction wave passes up the strip extending from the sinus to the bridge, passes over and then after a brief pause goes down the part from the bridge to the ventricle and into the ventricle, resulting in contraction. By diminishing the extent of the bridge, then only every second contraction passes over, resulting in ventricular contraction, no response being made in the case of the wave stopped. If this bridge is made very small then there is no passage of contraction between auricle and ventricle and the ventricular contractions are entirely independent of the auricular. The nervous action according to Gaskell, in the case of nerves passing from auricle to ventricle, conveys impulses from the ventricle to the heart, regulating the blood supply, increasing the conductive power of the auricle substance. He suggests that the influence of the vagus is to assist and render more efficient functional activity being the trophic nerve of the heart; upon its relation to the heart depending the character of the heart functions and their intensity as these functions are discharged by the cardiac muscle. In the cardiac muscle, which differs from the striated and unstriated muscle, the rhythmic activity is most perfectly developed. Hence he concludes, that the apparently opposite actions of the sympathetic and the vagus—upon the heart depends upon their connection with the process of heart nutrition.

The vagus exerts an anabolic influence, leading to and directing the processes of repair in the heart substance, while the sympathetic exerts a katabolic influence, directing the processes of decomposition by which the complex muscles are divided into simpler bodied. These represent the molecular changes taking place in connection with the cardiac muscle, the nervous influence being rather of a trophic nature. According to this idea, the rhythmic contraction of cardiac muscle is its special characteristic. This rhythmic tendency is found most fully developed towards the base in the tissues around the orifices by the large veins and in the auricle. This rhythm, originated in the region of the venous openings is transmitted through the auricles to the auriculo-ventricular groove; the rhythmic contraction of the ventricular tissue being produced by the electric variation arising from the rhythmic auricular, assisted by the increased cardiac pressure arising from the blood flow from auricle to ventricle. In the human heart these trophic influences are aided by the intra-cardiac ganglia, these in turn being influenced by the extra cardiac nerves. These nervous influences, however, are not the producers of the energy which manifests itself in cardiac contraction, but exercise an influence upon the cardiac pressure, and indirectly in this way govern the heart's action by securing the normal contraction of the walls of the heart cavities, and influencing the nutritive changes taking place in the muscle substance of the heart. In this way the ultimate solution of the cardiac rhythm depends upon the trophic influence of the nervous system upon the cardiac muscles.

PERSISTENCY OF CARDIAC MOVEMENT.

The heart continues to beat after it has been removed from the body. This movement continues longer in cold blooded animals, as the frog, than in warm blood animals. The heart of the frog will continue to beat for two or three days; a rabbit's heart from three to seventy-two minutes; in the case of the

right auricle, which is the ultimum moriens. The last trace of beating has been found in the rabbit 15 hours, and in the dog 96 hours after death, and in the human embryo the heart has been found to pulsate for four hours after death.

After the cessation of the heart beat stimulation may cause contraction. The ventricular contraction weakens first, then the contraction of the auricle is not followed by contraction of the ventricle, the ventricles contracting slowly, then ceasing to contract while the auricles continue to contract. Finally the right auricle ceases to contract. Even after stimulation fails to produce any contraction in the case of the heart by the injection of arterial blood into the coronary arteries the heart may be restored to pulsation.

Cardio-Pneumatic Movement.

During systole the heart occupies a smaller space in the chest cavity than during diastole. It follows from this that if the glottis be open, air will be drawn into the lungs when the heart contracts, whereas when the heart relaxes, air is expelled through the open glottis. Of course, account must be taken of the amount of blood in the larger vessels of the thoracic cavity. This circumstance seems of value in hybernating animals, as the movements of the lungs assist the exchange of oxygen and carbon dioxide, a sufficient air current being produced to aerate the blood as it passes through the lungs. Landois invented a cardio-pneumograph for the purpose of tracing these movements. It consists of a tube about one inch in diameter and six or seven inches in length. This tube consists of two parts, one for insertion into the mouth on the side of which is a valve to regulate the breathing and another part at right angles to the part inserted in the mouth attached to a metal capsule covered over with membrane. Attached to the membrane is a glass rod used as a stylus, which records the movements upon a recording glass plate. When the tube is placed in the mouth, the nostrils are closed the glottis is open and respiration ceases. From the tracings we can see (1) an expiratory movement at the moment of the first sound, because the blood is pouring into the right auricle through the venae cavæ and the dilating branches of the pulmonary artery compress the bronchi, the blood of the right ventricle passing into the pulmonary circulation. (2) A strong inspiratory movement follows, because more blood passes out of the chest than enters it through the vena cavæ. (3) After the semilunar valves have closed, arterial blood accumulates in the chest and hence, another expiratory movement follows. (4) the blood rapidly passes from the arteries in the chest outside of the chest and there follows an inspiratory movement of the air in the lungs. (5) then follows the flow of blood into the heart through the veins, followed by the heart beat.

Influence of Respiration Upon Cardiac Action.

The thoracic cavity contains within it, as an air tight compartment, the heart and the lungs. As the chest increases or decreases in size during inspiration and expiration, a certain amount of pressure is exerted upon the heart and influences, to some extent, its movements. During inspiration the diaphragm descends and the ribs are raised while the lungs expand, thus increasing the chest cavity. The pressure upon the external surface is less, the heart being in a condition of diastolic dilatation. During inspiration also the pressure is removed from the large veins entering the chest at the right side of the heart, and the flow of venous blood toward the heart is assisted. If after a very deep expiration the glottis is closed so as to prevent the admission of fresh air to the lungs, and if the chest be then distended by a very strong inspiration, the heart becomes dilated, this dilatation being increased by the

elastic drawing of the lungs. The venous blood flows into the right side of the heart, the blood is sent on to the lungs and thus the lungs become gorged while the left side of the heart cannot drive out sufficient blood into the arterial system. The pulse may disappear, the heart being distended and the lungs congested, while the arterial system contains but little blood. This is called Muller's experiment. During expiration the pressure on the external surface of the heart is increased and also on the external surface of the large veins, while only a small quantity of blood flows into the heart at its right side, the heart being contracted and the pulse beat small. In the Valsalva's experiment this is is increased. A very deep inspiration is taken and then the glottis is closed. Immediately a powerful expiration is made. contracting the cavities of the chest and heart so as temporarily to interfere with the blood circulation. The air in the lungs is under high pressure and it acts strongly upon the heart and thoracic cavity. Hence the veins in the face and neck become swollen, the blood from the lungs is quickly forced into the left ventricle, passing it into arterial circulation. The heart and lungs in this condition have little blood while systemic circulation there is a large quantity of blood. The heart sounds cease and the pulse disappears, indicating syncope. These represent abnormal conditions. In normal inspiration the air in the lungs is under slight pressure favoring the flow of blood into the heart and diastolic dilatation; whereas, in expiration the pressure is higher, favoring the flow of blood out of the heart into the aorta and thus aiding the systolic empting of the heart.

Cardiac Sounds.

When the ear is applied over the chest, either by the ear itself simply, or by the use of the stethoscope, two sounds are heard, one directly from the apex. This is a dull, long and booming sound. The second sound that is heard from the base, is shorter, sharper, more sudden and more clear. The first sound is heard during the apex beat and corresponds with the ventricular systole; hence, called the systolic sound. The second sound follows the first after an almost inappreciable period of pause, and it corresponds with the first part of the diastole of the ventricle. Following the second sound, there is a period of rest, or the long pause, as it is called, lasting till the commencement of the first sound in the next succeeding ventricular beat. This period of rest, therefore, corresponds with the latter period of the ventricular diastole, and also, with the systole of the auricles. These two sounds differ in their character. The first as we said, is low and presents a muffled sound, while the second sound is high and distinct. A difference is noticeable when the sounds are heard over the apex and over the base. Over the apex the first sound is accentuated, while over the base the second sound is accentuated. These sounds are usually represented by the meaningless words, "lupp dupp, pause, lupp dupp, pause, representing the characteristics of the sounds. The duration of thsee sounds depends to a large extent upon the listener, that is, it is subjective rather than objective. Walshe has stated that in the cardiac cycle taking the base of ten in the cardiac cycle, the first sound occupies 4 parts of the 10, then the short pause occupies 1 part; after the short pause, of course, we have the second sound, which occupies two parts, and the 3d sound three parts.

Much difference of opinion exists as to the cause of the first sound; this first sound may be heard distinctly after the removal of the chest wall, indicating that the heart beat does not produce this sound. Some Physiologists ascribe this sound to vibrations in connection with the close of the mitral and tricuspid valves. Others regard it as due to the muscular contraction of the

tissue in the ventricles. Others say that it is due to the flow of the blood through the aortic and pulmonary openings. The most probable cause, however, is what is called the double arrangement, consisting of the first and second, the valvular element and the muscular element.

This 1st sound is not a short, sharp one, such as we would expect in the case of the sound produced by the vibration of the valvular membranes, neither does it seem possible that this long and dull sound could be produced simply by the flow of the blood. One thing is certain—that is, that in the nature of this sound, a muscular sound, differing in its quality from the normal muscular sound on account of the pecularity of the cardiac substance. Prevailingly this sound is muscular, and in all probability, modulated and modified by the vibratory action of the auriculo-ventricular valves. In the case of the still living excised heart, the first sound has been heard quite distinctly. For example: The heart of a dog was first loosely and then tightly ligatured in the venae cavae, the pulmonary artery and veins and the aorta. After the ligatures were made as tight as possible, the heart of the dog was excised and placed in the glass vessel and filled with defibrinated blood. In the experiment, the narrow bottom of the conical glass was closed, not with glass, but with artificial membrane, and this membrane was connected by means of a flexible tube with a stethoscope. On listening through the stethoscope the second sound was not heard at all, whereas, the first one was heard very distinctly at each contraction of the ventricle. In this case the heart was empty of blood so that the closure of the valves could not possibly produce this first sound. In addition to this, we have the fact that in abnormal conditions when the muscular walls of the heart are weakened. For example: in an advanced case of typhus fever, the first sound may disappear entirely. On the other hand, in the case of diseases of the mitral valves a sound may be heard quite distinctly, of a blowing nature. This blowing sound, in some cases, may hide and in other cases, it may change altogether the character of the first sound into that second blowing murmur. The reason being that the sound, blowing sound, becomes so strong that it seems to over-bear the other sound and prevent, not the sound itself, but the communication of the sound. From this we conclude that the valves in their vibrations, give rise to a sound which becomes blended with the muscular sound produced by the heart substance and resulting in what we call the normal first sound of the heart. Wintrich, a German physician who has investigated this subject, by the use of the stethoscope combined with a resonator, has been able to detect in the first sound two elements, one part or element, on a high pitch, which he ascribed to the vibration of the auriculo-ventricular valves, and another part on the low pitch, due to the muscular cardiac contraction.

The second sound has been known very distinctly in its character since the time of the Physiologist Laennec. This sound, according to Laennec, was due to the sudden vibrations caused by the sharp closure of the sigmoid valves, when the diastole of the heart has just commenced. This sound is best heard over the 2d left costal cartilage close to its junction with the sternum. It is at the point where the aortic arch approaches close to the surface and hence, transmits conveniently the sound to the surface. Williams, one of the Physiologists, found that this second sound could be heard by applying the stethoscope directly to the heart. By passing a curved wire through the pulmonary artery the semilunar valve was hooked up. The aortic semilunar valve was similarly hooked up. In this condition the second sound had disappeared altogether and could not be heard. On withdrawing these obstructions the hissing murmur which existed while the valves were suspended had given place to the second normal sound. As we said before, the aortic and pulmonary valves do

not close simultaneously, they have a brief, a very brief, interval of time between their closure. If this interval be lengthened, we have what is called the reduplicated second sound—that is, the double second sound—one sound arising from the aortic and the other sound from the pulmonary artery.

During the first sound we find the following phenomena: (1) Ventricular contraction, (2) closure of the tricuspid and the mitral valves, (3) the flow of blood into the aortic and pulmonary arteries, (4) the heart beat, (5) the auricles filling with blood. During the second sound we find the following phenomena: (1) The closure of the semilunar valves, (2) relaxation of the walls of the ventricles, (3) opening of the tricuspid and mitral valves so as to admit the passage of the blood from the auricles to the ventricles, (4) diminution of apex pressure against the chest wall. During the long pause which is marked by the three tenth portion of the cycle we have (1) the auricle being filled with blood by the passage of blood from the ventricle, (2) auricular contraction, expelling all the blood out of the auricle into the ventricle. The short pause the one occupying the 1-10 period, the time is almost inappreciable and it may be said to represent the maximum of contraction in the case of the ventricle.

SECTION V.—The Heart in Isolation.

It is important to study the heart in isolation, because there are so many phenomena of importance in connection with the isolated heart. Many methods have been invented to study the heart movements in this isolation. The crudest method is to place the frog under the influence of curare, then placing it on its back on a cork plate to which is adjusted a fine lever that can be placed over the beating heart after the removal of the anterior wall of the thorax. In this way the movements of the beating heart communicate the impulse to the moving stylus attached to the lever which will record its tracing on the kymograph. If the heart excised from the frog is placed on a copper plate and over the heart a lever attachment be placed, it will be found by heating the plate that the heart beats more quickly, as the heating process increases until it passes into the tetantic state due to the thermal stimulation.

This tetenus will pass away on cooling the plate with ice. By the use of Marey's cardiac forceps the heart's movements can be noticed very distinctly. The frog is placed upon a plate so that two small cups can be placed over each side of the heart, each cup is connected with a horizontal bar over the top by means of two vertical arms, the one arm fixed and the other arm movable, the movable arm bearing a very small horizontal lever. At each systole of the heart the forceps will open and the lever will move and this movement will pass through the movable arm to the horizontal bar, this movement being communicated to a recording instrument.

Roy, another, Physiologist, has invented an ingenious instrument which he calls a tonometor for the purpose of studying those influences that act upon the beating heart under isolation. This instrument consists of a bell jar whose rim rests easily upon a greased groove in the brass plate. Through the jar stopper there passes a perfusion cannula to which the heart is attached so that the blood may continue to flow through the heart. At the center of this brass rod there is an opening through which an aluminum piston works. Around the edge of the lower end a fine membrane is stretched loosely. The middle of the membrane is connected to the upper surface of the piston, so that when the piston moves the membrane moves with it. The piston is connected with a fine rod to which a lever is attached underneath. The vessel is filled with olive oil and the heart is suspended in this fluid.

During diastole the heart expands, pressing down the piston rod and the point of the lever is connected with the recording kymograph. When the systole takes place the piston again rises, giving us tracings which are very characteristic of the heart's movements. In this way we have the tracings of the diastole and systole of the heart in isolation.

Nutrition of the Heart.

The heart is nourished by means of nutrient fluid carried to the different parts of the heart through the circulation. In the lower vertebrates this is secured, for example, in the frog, by passages going out irregularly from the heart cavities through the midst of the heart muscle close to the peripheral surfaces. These passages act as blood vessels, filling at each diastole and emptying at each systole, and, of course, conveying the blood to the cardiac muscle. In the rabbit, the cat, and the dog, and especially in man, heart nutrition takes place by means of the well developed cardiac circulation, the cardiac circulation being carried on through the coronary arteries and veins. In the case of the dog the coronary arteries and their branches are very close to the heart surface, the pericardium furnishing their covering. The left coronary artery originates at the aortic orifice, dividing into two branches, called the circumflex, and the desendens branches. The circumflex branch passes transversely outwards in the left auriculo-ventricular furrow, passing around the left side of the heart to the posterior surface and supplying with blood the left auricle and the upper anterior and posterior parts of the left ventricle. The desendens branch runs down the anterior inter-ventricular furrow to the apex of the heart giving out a number of branches to the left ventricle and to the anterior portion of the septum ; supplying with blood the septum and the inferior anterior portion of the left ventricle. The right coronary artery arises from the aorta just above the free margin of the anterior semilunar valve, passing to the right auriculo-ventricular furrow or groove around the right side of the heart, running as far as the posterior inter-ventricular furrow, where it divides into two branches. The right coronary artery supplies the right auricle and the right ventricle with blood. The small branches of the coronary arteries enter into the cardiac substance ending in the capillary plexus which carries the blood to the heart substance. Out of these roots originate the cardiac veins which carry the venous blood to the right auricle by means of the anterior cardiac veins and also the smaller veins, the foramina Thebesu.

Before entering the auricle, the large coronary vein becomes dilated, forming what is called the coronary sinus. At the junction of the vein with the sinus there is a valve, the other coronary veins which enter this large coronary sinus also have valves. The coronary arteries are terminal. at least, in man, that is, the anastomosis of the arteries does not produce a collateral circulation. This terminal character of the coronary arteries is of the greatest importance in connection with heart nutriment. The rapid closure of one of the large coronary branches in the case of the dog, for example, has been found to have little effect, some say, no effect at all, on the heart's action; others say it has a temporary affect, in producing an irregular action of the heart, or after a few seconds it may effect the ventricular action, producing what are called fib:illary movements. There fibrillary movements result from the shortening of the cells found in the cardiac substance. This arrest of ventricular activity depends upon the heart irritibility, and also upon the size of the vessel that is ligatured. When the force is sufficient and produces these effects, the ventricular pressure is lowered during systole and increased during diastole, resulting, of course, in diminishing the force of the ventricular contraction and also the ventricular

belaxation, sometime resulting in the cessation, altogether, of the ventricular hreat. Some physiologists have explained these changes upon the basis of anæmia—the scarcity of blood; others claim that these changes result from an injury to the muscles and also an injury to the nerves taking place during the process of ligature. In the latter case it is claimed that anæmia alone does not cause the fibrillary movements, whereas mechanical injury from the process of ligature does cause the stoppage of heart action. These statements however seem to lack confirmation by experiment.

The anæmic condition may produce these results. This can be shown by slowly interrupting the coronary circulation by the withdrawal of blood, in which case we find feeble inco-ordinated contractions. In this case the stoppage of the blood supply is slow, whereas, in the case of ligature the blood supply is suddenly cut off from the heart muscle. Some recent experiments have shown that even after such fibrillary contractions the normal movements of the heart may be again restored by establishing the artificial cardiac circulation, indicating the fact that these fibrillary contractions are only temporary. In the case of the valves entering the coronary sinus there seem to be two special functions discharged by these valves.

1st Function, intercepting the blood current during the systole of the right auricle, preventing regurgitation and the congestive condition of the walls of the heart.

2d Function, by the opening of these valves toward the auricle they prevent the backward flow of the blood during ventricular systole and aid the accelerated flow of the blood. It is during the ventricular systole that the blood enters the cardiac circulation and but for these valves the cardiaac circulation could not take place normally.

The coronary arteries arise, as we said before, at the aortic opening near to the sinus of valsalva, and as sinuses always receive sufficient blood to supply to the arteries, they can easily receive a sufficient blood supply during the ventricular systole.

In order to complete the nutritive process, the heart has its lymphatic system very fully developed underneath the pericardium and the endocardium and also, throughout the entire muscular substance. These lymphatics originate among the musclar fibres, the inter-spaces between the muscular fibers being lined with endothelium cells. Between the aorta and the trachea there lie lymphatic glands ascending along the trachea and terminating in the duct along the course of which the lymph is carried from the heart to the thoracic duct and also to the right innominate vein.

SECTION VI.—The Innervation of the Heart.

The nervous mechanism of the heart is most important and has been very fully investigated, because of the influence which the nerve centres exert upon the heart and the heart's action and also because of the questions which arise in regard to the relation of muscular action and nervous action in connection with the heart beat. The nervous mechanism has a double bearing. 1st, upon the heart as the center of the entire vascular mechanism, and 2nd, upon the changes that take place outside of the heart, especially in connection with the minute vessels. The heart really regulates and brings together the varying activities of the different parts of the body, while in turn, the heart is regulated by the nervous system. It is by means of the nervous system that a fuller supply of blood exists during work than during rest, and especially the work of the heart is so moderated as to meet and overcome the constant strain upon the heart substance.

It has been known for a long time that the heart of the frog can be kept beating after its entire removal from the body for many hours—normal beating, we mean—and even after the cavities are entirely empty of blood. This has been accomplished in the case of the heart of the dog and cat and the rabbit, indicating this fact, that the cause of the rhythmic heart beat must be somehow in the heart itself and not in its connection with the central nervous system. We have already discussed the causes producing this cardiac movement and we have found that it is due to the muscular contraction, a muscular contraction kept sustained by the impulses found either stored in the ganglia or communicated by the nerve fibres. This muscular contraction then is dependent upon the trophic influence of the nervous system. The heart beat, therefore, the normal action of the cardiac substance and the nutrition of the heart substance depends upon the nervous system and hence shows the importance of the careful study of the innervation of the heart. The view has been maintained that as the pulsations cease—that is of the heart—under ordinary circumstances in the following order: the lower part of the ventricle toward the apex, the entire ventricle, the auricles and then the sinus venosus, and as these parts in an inverse order represent a series of ganglia, much more numerousin sinus venosus, and altogether absent in the lower ventricle; therefore, it is concluded that the rhythmic heart beat depends upon the nervous impulses originating in these ganglionic nerve cells, passing down different fibres to the different parts of the heart, causing the rhythmic fiber contraction, which cordinate by the co-operation of the different ganglia. This would make the muscular fiber passive in the hands of the ganglia centers, but as we have seen this is not the case. The strongest impulse in contraction being muscular, this being sustained by the trophic influence of the nervous system. In the innervation of the heart we have to consider: (1) the extrinsic or extra-cardiac nervous mechanism, including the nerve centers and the great nerves connecting the heart with the central nervous system; and (2) the intrinsic or intra-cardiac nervous mechanism, including the nervous arrangement of the heart.

Extrinsic Nervous Mechanism.

This mechanism consists of nerves branching off from the cerebro-spinal and sympathetic systems so that the cardiac nerves are branches of the vagus and sympathetic, arising in the region of the inferior cervical ganglion. These nerves form two groups, one internal and one external. The internal group comprises a medium sized nerve, springing from the inferior cervical ganglion, a thick nerve springing from the trunk of the vagus near to the origin of the inferior laryngeal nerve and several fine nerves which arise from the vagus terminating in the cervical plexuses. The external group consists of an upper nerve originating in the inferior cervical ganglion or in the vagus trunk close to the inferior cervical ganglion, and a lower nerve arising in the lower curve of the annulus of Vieussens or sometimes, from the vagus close to the annulus.

In the year 1845, the Weber brothers discovered that the stimulation of the vagus trunk in the neck or at its deep origin in the grey matter on the floor of the fourth ventricle, produces in the case of a feeble excitation a lessening of the number of the heart-beats and in the case of a strong excitation it produces the entire arrest of the heart's action. This arrest of the heart's action taking place in diastole and by a gradual filling of the heart with blood. Having found that the inhibitory power resided in the medulla, the question then arose "how was this impulse transmitted to the heart?" By a section of the pneumogastric it was found that the action of the heart was accelerated, while on stimulating the cut end of the peripheral portion, the heart's action

was slowed, and in some cases completely suspended. The influence of the pneumogastric fibers, therefore, on the heart is inhibitory or restraining. From this experiment we conclude the action of the vagus upon the heart is inhibitory or restraining. The slowing and arresting of the heart's action may be produced by different kinds of stimulation ; for example : chemical stimulation, or mechanical, as well as electrical stimulation. One Physiologist has discovered that the pressure of the carotid artery at the anterior margin of the sterno mastoid would result in slowing of the action of the heart which he supposed to be produced by the stimulation of the pneumogastric. During this arrest of the heart, the heart does not cease to be subject to irritation, for during this inhibitory action it will still respond to stimulation. This arrest of the heart action is not due to reflex action, but is direct, because this arrest will take place on excitation or stimulation of the peripheral end of the cut nerve. This inhibition is not constant.

The right vagus seems to have a greater influence on the heart than the left vagus, and it is found, on excitation of the vagus, the auricles of the heart in particular are affected—that is the part of the heart affected by stimulation of the vagus, is the auricle. This influence of the vagus affects, not only, the frequency of the heart's pulsations, but also, the strength or the force of these pulsations. This is evident from the fact that on the stimulation of the vagus, the pulsations become fewer in number and, also, each pulsation becomes more feeble. This stimulation of the vagus may be increased by the section of the spinal cord, and also of the sympathetic in the upper portion of the neck. This excitation of the vagus affects the periodicity of the ventricular action, particularly the ventricular systole; the feeble stimulation of the vagus greatly increasing the period of diastole, and also the diastolic pressure. . A strong stimulation increasing, on the other hand, both the periods of the systole and diastole. Even in the case of the continued stimulation, however, the heart after several seconds begins to beat, at first very feebly, and then after a short period resumes its normal beating without removing the stimulation. The effect of this stimulation is to lessen the force of the ventricular contraction, increasing the quantity of blood at the close of the systole, and at the close of the diastole of the ventricle, diminishing both the amount of blood that is received and given out. The tone of the ventricle is also affected by this stimulation, being slightly diminished. The proof of this is found in the fact that the walls of the empty ventricle after stimulation, are found to be soft and flaccid, giving up, to a certain extent, the strength that is found normally in ventricular walls, due to the thickness, particularly of the one ventricular wall. In the case of the auricle, the excitation of the vagus, diminishes the force of its contraction, lengthening the diastole, these changes appearing earlier than the changes that are found in the ventricles, indicating what we do find, that the ventricle is affected through the auricle. In the case of strong stimulation of the vagus the heart does not contract at all, or at least with less vigor. A single electrical stimulation will not arrest the heart action at first, but if the stimulation be continued, it will affect the heart, different parts of the heart with varying intensity. Weak stimulation for example, affects the auricle and then indirectly through the auricle it affects the ventricle. Strong stimulation, on the other hand, stops the action of the auricle while the ventricle remains for a short period, unarrested and then stops. Very strong stimulation inhibits, not only the auricle, but also, the ventricle. It would seem from what we have seen, that the vagi, the right and left vagi, do not act directly upon the fibers of the heart, but rather upon the intrinsic nervous ganglia, although in what way this action takes place, we do not know.

It is probable, however, that the same intra-cardiac terminal acts for the two vagi, for when one vagus is stimulated till the heart overcomes the effect of stimulation the excitation or stimulation of the other vagus has no effect upon the heart at all. Gaskell, who has devoted much time and attention to this subject, accounts for the medium of the inhibition by the fact that the vagus is the trophic nerve of the heart. He thinks that after the stimulation is over, the heart becomes more vigorous, this being according to Gaskell the proof that the excitation of the heart through the stimulation of the vagus has nourished and made it stronger than it was before and, therfore, is considered to act more vigorously. As yet, however the experiments have not sufficiently established this point, although it seems very probable.

Bezolo discovered that after a section of the spinal cord between the first and second thoracic vertebrae the stimulation of the cervical cord produces an acceleration of the heart's action. This stimulation he found was carried or conveyed from the cord to the inferior cervical ganglion, from which center it passed through the nerve fibres to the heart. These accelerator fibres enter the sympathetic from the spinal cord, coming from the inferior cervical and the first thoracic ganglia, dividing so as to form the annulus of Vieussens and then joining the vagus trunk From the superior cervical ganglion fibres pass into the vagus, passing down the trunk into the cardiac plexus between the superior and inferior laryngeal nerves. The spinal nerves, from the 1st to the 11th and possibly to the 12th, send out fibres to the superior cervical ganglia, the sympathetic trunk and the first thoracic ganglion. This sympathetic acts as an accelerator, the section of the sympathetic even on one side being followed by the slowing of the heart's action, the heart being left to the action of the pneumogastric. If the cut end of the distal portion of the nerve be stimulated the heart will beat more quickly. The excitation also, of the fine fibres that pass into the heart from the inferior cervical ganglion accelerates the action of the heart or beat. These delicate fibres originate in the spinal cord for by separating the heart from the cerebro-spinal system and leaving the sympathetic fibres the stimulation of the higher part of the spinal cord also causes acceleration of the heart beat. The chief result of the stimulation is the increase in the heart pulsations, that increase being according to some Physiologists, from 10 to 70 per cent of an increase The force of the ventricular pulsation increases. The ventricle becomes filled more completely with blood and the quantity of blood that is ejected from the ventricle is also increased. The stimulation of the nerves on both sides of the heart does not increase the heart action more than the stimulation of the one.

Auricular contractions also increase in strength and in volume, this latter increase in volume depending upon the increased elasticity of the relaxed auricle. These changes, accelerator changes, give rise to an increased blood pressure in the systemic circulation of the arteries and to a fall of blood pressure in the pulmonary veins and venous circulation to the heart. If the vagi, the inhibitory nerves, are stimulated at the same time as the sympathetic; the auricular and the inhibitory or the vagi action will overbear the action of the sympathetic,indicating that inhibition is stronger than acceleration. Even if the stimulation of the sympathetic is continued for a long time, and even if the stimulation is very strong and severe, the heart will not pass into a state of tetanus, but after quickening its pace for a short period it will return to its normal rate. This indicates that the accelerator fibres or nerves are not motor nerves of the heart. The sympathetic nerves fibres do not act directly on the heart muscle, but rather on the intra-cardiac ganglia causing them to give out their entire reserve stock of energy. When this stock of energy is exhausted

the stimulation of the sympathetic will fail to accelerate the heart's action. This seems to indicate one line of proof in the direction of Gaskell's idea that the vagi nerves act as trophic nerves by which the heart is nourished. The nerves are not irritable, hence Gaskell says we should not use the word irritable at all in connection with the vagi—we should use the word stimulation.

In the trunk of the vago-sympathetic and from the loop of the annulus of Vieussens certain fibres originate and pass to the heart which are not properly either inhibitory or accelerator nerves. For example, it has been observed that if the intra cardiac vagus act so strongly as to arrest the action of the auricles, excitation of the vago-sympathetic trunk will result in a marked increase in ventricular and auricular activity. This usually followed by an increase of the heart's action or beat. These changes are not purely inhibitory. Pawlow has classified the inhibitory and the accelerator nerves under four heads. 1. Those which inhibit the heart beat. 2. Those which inhibit the force of contraction. 3. Those that increase the heart-beat, and 4. Those which increase the force of contraction. Thus we have the inhibitory and accelerator force with two subdivisions of each. For example: It was found that in certain stages of poisoning by convallaria majalis that the stimulation of the vagus at the neck when all its branches were severed except those going to the heart and lungs were divided, that the blood pressure was lessened without affecting the heart beat. The stimulation of different branches from the annulus of Vieussens leading to the heart was found to produce in some cases a diminisbed blood pressure, and in cases of other branches a reduced heart beat, and in others an increased blood pressure independent ot any other results. This seems to lead to the conclusion that certain nerves act upon the heart rhythm and others upon the contraction force forming the basis of the sub-division of Pawlow already mentioned.

The Reflex Action of Some Sympathetic Fibers and of the Cerebro Spinal Nerves.

In the sympathetic there are fibers which excite reflex action through the vagi. If the sympathetic nerve is divided at the neck and the cephalic portion of the nerve is stimulated, the heart's action becomes slow. This is explained by the fact that certain fibers of the sympathetic communicate through a center or centers with the vagus. Stimulation of these fibers arouse the activity of the center, and this activity is communicated by the center to the vagus. The cardiac ganglia, in this case, being inhibited and hence, the action of the heart is slowed. This will not take place if the vagi have been previously divided, or cut.

Gotz, one of the German Physiologists, has proved this by several experiments in connection with the frog. The chest-wall was cut by him, in such a way, as to expose the pericardium, through which the heart pulsations could be easily observed. By beating upon the abdomen with the end of the scalpel, the heart was gradually slowed, and finally the heart ceased to beat altogether. On stopping the beating on the abdomen, the heart rested for a short time and then began to beat more quickly than in its normal condition. Thus the fibers of the sympathetic in the abdomen, on being artificially stimulated—in this case it was mechanical stimulation—produce a reflex inhibition of the heart through the vagi. The stimulation of the central end of the splanchnic is found, also, to produce reflexly a rising blood pressure and the slowing of the heart's action. According to some Physiologists, splanchnic stimulation produces not a simple but a compound result; the stimulation resulting in increase due to the acceleration and inhibition toward the close of the stimulation. It has been found that a severe blow on the epigastrium or the sud-

den swallowing of a large quantity of ice-water produces syncope of the heart The dilatation of the stomach has been found to produce an inhibition of the heart. The stimulation of the sensory nerves seems to affect both the accelerator and inhibitory fibers. In the case of a weak stimulation the accelerator influence prevails and in the case of a strong stimulation the inhibitory influence prevails. The stimulation of the nerves of the special senses, sometimes increases and sometimes diminishes the action of the heart.

The strong irritation of the suborbital nerve has been found to arrest the action of the heart in diastole. The stimulation of the central end of the cut vagus causes, at least, a slowing of the heart beat, some say its complete arrest. If the vagus, on the other side, be cut, this slowing will disappear altogether, indicating that the stimulation of the central end of the one affects the heart through the other vagus—that is, it is a reflex action. At the same time the blood pressure is affected; sometimes it is lessened and sometimes it is increased, the difference in this case being due to the vagus which seems to differ in different individuals.

DEPRESSOR NERVE.—This nerve is sometimes called after the names of the parties who discovered it, Ludwig and Cyon. These two Physiologists finding that the stimulation of the nerves passing from the central nervous system to the heart aside from and independent of the vagus produced no effect upon the heart rate or the blood pressure, thought that this was due to the fact that the excitation was limited to the end of the divided nerve still in connection with the heart. They thought that stimulation of the end connected with the brain would produce, not negative, but positive results. In their investigations in connection with these nerves in the rabbit, they found an afferent nerve springing from the vagus, high up in the neck, the stimulation of its central end, producing a fall in the blood pressure. On account of its action, they called it the depressor nerve. This depressor nerve arises from two or more nerve roots, one of which springs from the vagus, and another from one of the vagi branches of the superior laryngeal nerve. If this nerve is single in its origin as it is sometimes, its origin is found in connection with the laryngeal nerve. Side by side, with the cervical sympathetic, it runs down to the chest where it communicates with the ganglion stellatum by some of its branches; the depressor fibers terminating in the ventricular walls of the heart. In the case of the dog, it is joined to the vagus and does not form an independent nerve. The depressor nerve is exclusively an afferent nerve. After it is divided on the stimulation of the peripheral end no effect is noticed in the heart rate, or the blood pressure. From this we conclude that the heart terminals in this nerve are quite distinct from the endings of the inhibition nerves or vagi, and also, independent of the ending of the accelerator nerves of the sympathetic. If the central end of the cut depressor is stimulated, a gradual fall of blood pressure follows, and at the same time there is a gradual diminution of the heart rate. On withdrawing this stimulation the blood pressure is restored to its normal condition.

If both the vagi are cut the excitation of the depressor nerve causes no change in the rate of the heart, but there is a fall of the blood pressure. From this we conclude, (1) that the change of the heart rate is produced by the stimulation of the cardio inhibitory center, the vagi acting as the medium through which the action affects the heart, and (2) we conclude that the change of the blood pressure does not depend upon the vagus remaining perfect or intact, for on the section of the vagi the pressure of the heart or the blood still continues to fall. By transmitting an impulse to the cardio-inhibitory center, the center is inhibited and its activity being restrained the small arteries dilate

and as a result there is a fall in the blood pressure. Normally, this center, that is, the cardio-inhibitory center is engaged in transmitting impressions which keep the muscular fibres of the arteries in a tonic state of contraction. This action being inhibited, the fall of blood pressure results on account of the lessening of the peripheral resistance. Poisoning by curare does not seem to affect the depressor nerves. There are two possible causes of the fall of the blood pressure. 1st, the cause may possibly be in the heart itself. This, however cannot be the case, because after all the nerves to the heart have been divided, depressor stimulation still continues to lower the blood pressure. (2) therefore, we are left to the other conclusion that the cause must lie in the arteries. By dividing the splanchnic nerve it was found that the abdominal arteries were dilated and the blood pressure fell. Excitation of the peripheral end of this divided splanchnic nerve on the other hand caused a rise in the blood pressure, whereas the stimulation of the central end did not produce any affect upon the rhythm of the heart or upon the blood pressure. This led these experimenters to conclude that the depressor nerve causes a fall of the blood pressure by lessening the tonic constriction of these arteries under the influence of the splanchnic nerve, resulting in arterial dilatation and the lessening of peripheral resistance. The depressor fibres connect the heart with the vaso-motor center, these fibres connecting with the vaso-motor center being stimulated when the heart becomes overfilled with blood, this stimulation passing through the fibers and the vaso-motor center and affecting the arteries under the splanchnic nerve, lessening the resistance and thus aiding the overfilled heart in emptying itself again. Thus the function of the depressor nerve is temporary, not continuous. This is evident from the fact that the section of the depressor nerve does not alter the blood pressure at all.

Some recent investigations have shown that the excitation of the depressor nerve after placing a limb of the body in Masso's Plethysmograph resulted in the increased volume of the limb due to the dilatation of the arteries in the limb. The same effect is noticed in connection with those vessels in the neck becoming very much dilated just in the same way as the vessels in the limb.

Centers of the Cardiac Nerves.

In connection with the heart there are three great centers: 1, An inhibitory center connected with the inhibitory fibers of the vagi. 2. An accelerator connected with the sympathetic fibers, and 3 The higher cerebral centers sometimes called the higher centres, which influences these other centers and explains in some way the relation of the emotions to the heart and the heart's action.

1. Inhibitory Center. The Webers, two brothers that we have been referred to already, found that this inhibitory center was located in the medulla-oblongata. Its exact location in the medulla has not yet been identified because, while a stimulation of the various parts of the medulla may yield certain results, it is difficult to distinguish the effects that are produced by the excitation of the center itself, and by the excitation of the nerves after leaving the center. Laborde has localized this center at the level of the nucleus of the hypo-glossal nerve (the 12th nerve), the vagus and spinal accessory, in the grey matter on the floor of the 4th ventricle. It was found that by separating the bulb from the spinal cord, all the reflex actions induced by nerves entering the cord were suspended while the reflex action resulting from the excitation of the tri-facial nerve (the 5th nerve), remains undisturbed. From this it is concluded that the inhibitory center is contained somewhere in the medulla, but exactly where is not known. The center of the inhibition seems to be

always active, for if the vagi are divided the heart-beat increases. This constant activity of the center may be due either to constant impulses conveyed along the afferent fibres or to the independent activity of the center apart from these afferent impulses. It would seem that the division of the vagi after all the afferent impulses have been destroyed by section of the spinal cord below the bulb does not increase the heart-action. These nervous impulses come to the center of inhibition by sensory nerves from the periphery, the splanchnics, from the abdominal cavity and also through the depressor nerve from the heart. If the splanchnic nerve be cut the afferent impulses are suspended and the heart rate is increased. The origin of the cardio-inhibitory fibres is uncertain, although it is generally believed that they enter the vagi from the spinal accessory nerves, (the 11th pair of nerves.) This is believed to be the case because on removing the spinal accessory before it joins the vagus trunk and allowing the fibers in the vagus to degenerate, cardio inhibition is destroyed, entirely destroyed. This, however, is disputed by some physiologists.

2. ACCELERATOR CENTER.—The accelerator fibers are believed to originate in the upper portion of the spinal cord, the situation of the center being unknown, although it is probably in the bulb. The accelerator center seems to be always active. This is evident from the fact that the heart rate is lowered after division of the vagi followed by the removal of the inferior cervical ganglion and the first dorsal ganglion. The same result is produced—that is, the lowering of the heart rate—by the section of the spinal cord of the upper cervical portion after the division of the vagi. There is a reflex acceleration of the heart action that arises from changes in the cardio inhibitory center and not due to the direct accelerator stimulation. If the accelerator fibers are divided, the vagi remains perfect so that the stimulation of afferent nerves increases the heart's action. It makes no difference, then, whether the acceleratory nerves are divided or solid, the stimulation of the afferent nerves produces the same result.

3. THE HIGHER CENTERS.—Various efforts have been made to localize as well as to discover higher centers, especially, in the cortex cerebri connected in some way with the inhibitory and accelerator action of these centers. Such attempts, so far, have been unsuccessful. The heart's action in connection with the heart-beat is not to a very great extent, if at all, subject to the voluntary control of the will except in very rare cases. There is no doubt but there is some connection between the higher centers representing the emotions and the cardiac centers, but the nature of these connections is as yet unknown.

INTRA-CARDIAC NERVOUS ARRANGEMENTS.—This subject has been investigated chiefly in connection with the heart of the frog. This is of considerable disadvantage in the study of the mammalian heart, for the frog's heart is more subject to intra-cardiac regulation than the mammalian heart. In the case of the frog, for example, the vagus seems to act as an inhibitory, not constantly, but only under extraordinary circumstances. When the vagus of the frog is divided, there is no increase in the heart rate. The nervous mechanism in the case of the frog's heart, is very simple. The two cardiac branches of the vagus nerves lie along the walls of the inferior vena-cava, extending to the posterior margin of the sinus venosus, forming a ganglion where the sinus and the right auricle unite. The nerves then branch out along the auriculo ventricular furrow, toward and joining the two ganglia of Bidder. From these ganglia a number of fine nerves pass underneath the endo cardium and outwards into the muscular tissue. In the mammalian heart, on the other hand, a large number of non medullated nerves appear, forming themselves into networks, and running underneath the pericardium from the base to the apex

of the ventricle, running always in a slanting and oblique direction. These nerves can be traced to the cardiac plexus, situated at the base of the heart. They are not efferent branches of the vagus, or sympathetic, for even after dividing these cardiac nerves the characteristic inhibition and acceleration follow. If the peripheral ends of these cardiac nerves are stimulated, no effect follows in the heart rate, or in the blood pressure; but by the stimulation of the central ends, there are noticeable changes in the heart rate, and also in the blood pressure, indicating that these nerves—convey impulses to the central nervous system, resulting in a reflex action upon the heart. Some Physiologists think that the impulses are carried not from the cardiac nerves to the central nervous system, but from the cardiac nerves to the peripheral ganglia; the heart being influenced through these peripheral ganglia and not through the central nervous system. This raises the question whether the peripheral ganglia do, or do not, act as centers of the reflex activity. The excitation of the central end of the divided left anterior portion of the annulus of Vieussens becomes changed inside the first dorsal ganglion, into a motor influence transmitted by the posterior portion of the annulus. This impulse, thus changed, produces an acceleration of the heart reflexly. This would seem to indicate that certain afferent influence become changed in the sympathetic, particularly in the cardiac ganglia into efferent impulses which act upon the heart.

Experiments In Connection With The Heart.

After the removal of the frog's heart from the body and the breaking of all connection with the central nervous system, it still continues its rhythmical beat for some time. If then the apex of the heart is moved it (the apex) will cease to beat while the rest of the heart continues to pulsate. If the heart is continuously divided into transverse sections it will continue to beat until it is divided at the auriculo-ventricular furrow when the ventricle will cease to beat. If these unbeating parts of the dissected heart are stimulated they will respond by a single contraction even after they have ceased to beat. If the ventricle and the auricle be divided at the auriculo-ventricular furrow, the auricles will continue to beat, the ventricles ceasing. If, however, this division is made on the auricular side of the groove, especially if the septum be preserved intact the ventricle, in this case, will continue to pulsate, probably because of the passage from the auricle to the ventricle of an impulse. Gaskell by the use of the tight screwing instrument (the clamp) which he fitted around the heart was able to block entirely the nervous influences so that the ventricular beat, instead of being simultaneous with the auricular beat, beat only once for every three or four beats of the auricle. Stannius and Rosenberg have made experiments of considerable importance in this connection After exposing the heart the pericardium is opened, the connective tissue between the pericardium and the ventricle is separated so as to permit the ventricle to be raised Then a ligature is passed around exactly between the right auricle and the sinus venosus and another around the auriculo-ventricular groove.

The sinus continues to beat, the auricles and ventricle being stopped in diastole. After the latter ligature is applied the ventricle begins to beat again and sometimes the auricle also, but normally the auricle remains in diastole. It is supposed that the ganglion in the sinus affects in some way in the normal heart, the ganglion in the furrow. When the sinus ganglion is cut off, the auricle and ventricle stop because the ganglion in the groove has not enough energy to keep up the activity. The stimulation of the latter ganglion causes both auricles and ventricles to beat again, if any part of the ganglion is connected with the auricle and a part with the ventricle. This does not imply that the ganglia are neces-

sary, however, to the heart-beat. For if the ventricle of a frog's heart is divided into sections, each part connected by muscle to each other part, stimulation of one part will cause the other parts to beat. In this case the rhythm is not transmitted by nervous impulses. This indicates that the rhythm takes place in structures which have no nervous ganglia, as in the apex of the heart and in the heart of the fœtus in its earlier stages of development.

OTHER CIRCUMSTANCES INFLUENCING THE HEART RHYTHM. While the nervous system affects the heart, there are other influences which affects it. These are two-fold: 1. Influences depending on nutrition, and 2. Physical, mechanical and chemical influences. 1. The heart substance needs nourishment, and for this the blood supply of a necessary quality and quantity is required. In the case of the frog's heart, it continues to beat after being removed from the body and empty of blood. Soon the beating ceases. This will be aided by washing out the tissues with a saline solution If after washing a heart in this way it be attached to a perfusion canula the heart may be fed with suitable fluid, such as diluted blood or blood serum passed through the canula In this way the heart-beat may be restored artificially and kept up for a long time. When fed in this way it is found that certain substances like lactic acid result in expansion while others, like solutions of sodium hydrate, result in contraction of the ventricle. This means that the ventricular portion. of the heart possesses tonicity varying with its condition and circumstances; for example: the presence of inhibitory or accelerator impulses The rhythm thus artificially produced by artificial feeding becomes generally very soon intermittent, due both to the formation of certain chemical substances and to the fact that artificial feeding is not as perfect as natural. Thus influences arise, connected with the heart nutrition, which affect the beat by influencing in some way the muscular tissue and also the nervous tissue, producing variations in the heart rhythm.

During life the heart beat is maintained by the constant supply of arterialized blood. The blood is so complex that all its elements are not of equal value to the heart for its nutrition. Various experiments have been employed by different Physiologists to discover the constituents of blood necessary for heart nutrition. A frog's heart,—for example,—supplied with a normal saline solution six per cent solution of sodium chloride, ceases to beat sooner than an empty heart. Certain of the salts that are found in the blood are required to sustain the action of the heart. For example: Sodium chloride solution, a one per cent chloride solution, is said to be isotonic. A calcium salt added to the heart after the addition of sodium chloride prolongs the heart beating, although at the same time it alters the contraction, specially the contraction of the ventricle, which falls into what is called a condition of tonic contraction. By the addition of potassium salt, the normal condition of contraction may be restored. Ringer recommends the following compound solution:

Sodium chloride, a 6 per cent solution, saturated with tribasic calcium phosphate, a hundred cubic centimetres; Potassium chloride, 1 per cent solution or acid potassium phosphate also 1 per cent solution two cubic centimetres. In regard to the mammalian heart, little has been discovered except that the blood of the same species is the best nutriment to supply the heart. It seems that in supplying the mammalian heart with the blood of a different species the heart is caused to cease beating sooner, œdema being set up in the lungs resulting in the gorging of the right side of the heart and the obstruction of the pulmonary circulation, resulting finally in the injury of the elastic cardiac muscle, causing distension, so that the diastole of the heart is impossible.

2. THE PHYSICAL AND CHEMICAL INFLUENCES.

These influences affect the structure of the heart, both muscular and ner-

vous. We have seen already that the beat of the frog's heart is affected very materially by the beat, increasing the pulsations. The number of pulsations in the heart are increased until 40 degrees C. is reached, when the heart passes into a condition of thermal rigor. Up to 20 degrees C. the extent of the contraction continues to increase; above 20 degrees C. it diminishes, the contraction being more rapid and also of shorter duration. The cooling of the heart—as we saw, by ice—removes the rigor and by the continued application of the cooling process the heart is normally restored until it reaches 3 or 4 degrees C. when it will cease to beat. Even if the heart—the heart of the frog—is frozen, by the application of heat gradually so as to thaw out the heart not all at once but slowly, the heart will revive and begin to pulsate after a few moments, normally. In the mammalian heart it is found that by severing all the nervous connection and pouring into the heart warm blood at the normal temperature it begins to beat faster, whereas, it beats slower if a cold solution, as cold blood, is poured into the heart. It has been found that the heat must be applied to the blood in the capillaries of the heart in order to produce these results, indicating that the heart must be brought into contact with the heart substance through the blood in order to effect this increase. This idea is of great value in considering the abnormal conditions represented by fever pulsations, which become very rapid.

If an electric current is applied to the heart, of a moderate strength, the heart beat is quickened, whereas, if the current applied is very strong, the heart passes into the condition of fibrillation. A minimal stimulus produces a maximal contraction. If the stimulus is applied to the heart the effect of the stimulation will depend upon the length of time that has elapsed since the last contraction of the heart. If the time that has elapsed since the last contraction of the heart, is sufficiently long to enable the heart to recover itself, a stimulation applied will result in still further contraction. If the time, however, has not been sufficient to allow the heart to recover itself, a feeble, electrical stimulation will call forth no response, while a strong stimulation will force a response. In this last case of a strong current of stimulation, there is a cessation of the heart's action, the muscle of the ventricle at least manifesting the characteristic twitching movement, the ventricles themselves, being so twisted and dilated as to prevent blood from being driven out. Certain chemical substances affect the heart; for example: ether in small quantities, increases the heart beat, at least, in the frog's heart, while large quantities of ether will arrest the action of the heart altogether. This arrest of the heart caused by a large quantity of ether can be overcome by the addition of fresh blood to the heart. Chloroform also diminishes the heart beat. Carbonic oxide and sulphuretted hyorogen act upon the heart so as to paralyze it. Excessive carbonic acid lessens the activity of the heart, and if it is very excessive, will stop the action of the heart altogether. Sulphurous acid also very rapidly destroys the activity of the heart. The potassium salts also stop the heart in diastole. A cholorine solution, if the solution is weak, stimulates the heart's action, whereas, if the same solution is strong, it arrests the action of the heart altogether.

SECTION VIII.—II. Circulation of the Blood in the Blood Vessels.

The circulation of the blood in the blood vessels depends upon certain physical principles that regulate the movements of the current in tubes, both elastic and rigid. In the circulation of the blood in these vessels, we have to take into account, first of all, the heart force. This heart force, as we have seen, drives out the blood from the heart into the arterial circulation. 2d We have to take into account the long stretch of elastic tubing reaching from the heart,

both backward and forward to the peripheries, and 3d. In the minute vessels there is a peripheral force which constitutes a constant resisting force, acting upon the blood backward to the heart. Apart from the heart rhythm, the elasticity of the arterial walls and the peripheral resistance offered by the minute capillary vessels, there are certain physical principles which explain many, perhaps all, the pheuomena of the circulation. The heart force meets the pheripheral resistance set in the capillaries, and sent back from these minute vessels in such a way as to promote the circulation through the entire vascular mechanism. In Physical Science the law of the equal transmission of pressure is as follows: That the pressure upon any region of the surface of a fluid, is transmitted equally, and always at right angles to any part of the surface of the fluid having an equal area.

If we take a vessel filled with water, the pressure at the bottom of the vessel will be equal to the weight of a perpendicular column of water equal to the height of the fluid, and with a base equal in area to the bottom of the fluid At any point along the side of the vessel, or tube, in which the fluid is contained, the pressure will be equal to the weight of a column, equal to the depth of that point below the surface of the fluid with a base whose area is equal to the area of the side of the vessel.

The rapidity of the flow out of such tubular vessels of fluids is in direct proportion to the cross section area and in inverse proportion to the length of the tube. If the tube in which the liquid is contained be uniform, the fluid will run through each cross section with a certain rapidity, this rapidity diminishing with the ratio of the length of the tube and also the amount of resistance that is met with the fluid within the flow. The rapidity of the flow of the fluid will depend upon a number of considerations: 1. The calibre of the tube. 2. The length of the tube. 3 The nature of the liquid, the glutinous fluids flowing slower than the limpid fluids. 4. The pressure velocity increasing with the square root of the pressure except in small tubes, when it increases directly with the pressure. 5. The temperature, the velocity increasing with the rise of temperature, falling with the fall of temperature. 6th. The resistance. The flow is slower where resistance is greater and vice versa. This resistence is increased by the curving, jointing or the folding of the tubes, and also increases by the branching of the tube. In the latter case the branching of the tube where the tube branches off into a number of divisions, the same liquid volume passes through the same cross section area, the velocity being inversely proportional to the cross section area, therefore diminishing as the cross section area increases. These are principles that we apply to the circulation, principles that explain the circulation of the blood. In passing from the arteries to the minute blood vessels this cross section area is constantly increasing. The blood starting from the heart has to begin with the force of the heart's action, This force is not constantly exerted, but only at intervals represented by the heart beat or the heart beat pulsations, these intermittent pulsations being compensated for by the elasticity of the arteral walls so that when the blood reaches the capillaries it is a continuous stream. This continuous current passing along the elastic arteries bears along with it the wave of contraction, representing the amplitude of the heart pulsations, the current being slower than the wave which passes along the walls. Several experiments have been made by Marey and others in connection with elastic tubes through which a fluid is passed intermittently as in the case of the blood. The results may be summarized: 1. A fluid on entering the elastic tube intermittently and quickly arouses a series of waves transmitted with a velocity independent of the current of the fluid. 2. The velocity of transmission in pro-

portional to the elasticity of the tube and in an inverse proportion to the fluid density. 3. The extent of the wave depends upon the amount of fluid and the rapidity with which it is thrown into the tube. 4. If a fluid enters the tube in a large volume there is a backward oscillation which causes secondary waves. 5. In branching out of one tube into two tubes a very complex series of waves passes along the one tube into the other. This never takes place in the arteries because each artery has its own peculiar wave and never communicates it to the other. 6. If an elastic tube becomes suddenly narrowed or if the quantity of fluid is quickly increased or diminished a negative wave is set up. These represent the physical principles which will be applied to the circulation of the blood.

In the living circulation we find certain elements that are not found in any artificial representation of it. In the venous circulation there is such a valvular arrangement as to materially assist the circulation from the capillaries to the heart, and to prevent any recurrent blood flow. Muscular movements, especially these movements of the skeletal muscle, and even the passive movements of the limbs will assist the circulation. In respiration, also, the contraction and distension of the thoracic cavity tend to force the blood out of the chest and to draw the blood back again into the chest from the outside, thus promoting normal circulation. All these actions of the human body act as material helps to the circulation. We must remember, however, that these are simply aids that do not, or cannot, produce the circulation, because even when the muscles are resting, and when respiration is suspended for a time, there is force enough generated in the ventricular beat to drive the blood through the arterial circulation, through the capillary circulation, and through the venous circulation back to the heart again.

SECTION IX.--Physiology of the Structure of the Blood Vessels.

The blood vessels consist of arteries conveying the blood from the heart to the capillaries, through which the blood passes in close relation to the tissues of the body and to the lymph, emptying itself into the veins which carry the blood back again to the heart. The arteries, as we have said, carry the blood away from the heart. These arteries in their structure are very important. They have a strong elastic wall, and hence, remain open, even when they are cut transversely. Each artery is surrounded by a sheath of connective tissue, more or less distinct, and the arterial wall consists of several layers or coats. 1st. The tunica intina, a delicate transparent, easily broken coat, arranged longitudinally. 2nd. The tunica media, or thick, tough, elastic and contractile layers, composed of unstripped muscle fibres, arranged circularly around the vessel and in the large vessels, it consists also, of a large portion of elastic tissue. 3d. The tunica adventitia consists of bundles of connective tissue, with some muscular fibers mingled among them; these muscular fibers being situated chiefly in the deep part of the tunica, suitably arranged, also, longitudinal.

There are three kinds of arteries. 1. The arterioles, those that enter into the capillaries. 2nd. The medium sized arteries, including all the larger arteries except the aorta and pulmonary artery. 3d. The large arteries, containing a very large amount of elastic tissue. This composition of the arterical wall makes the arteries, (1) very elastic so that they distend readily, either longitudinally or transversely, returning rapidly to their original position when the pressure is removed. This elasticity is of great value in maintaining the circulation; (2), the arteries are also very contractile. On being stimulated, eather mechanically, electrically, or by nervous impulses, they lessen in calibre reducing the bore of the artery. Thus the calibre of the artery may be widened

or narrowed according to the muscular activity of the arterial walls. In the larger arteries there is a predominance of the elastic fibers, and the smaller arteries of the muscular fibers—giving to the larger and to the smaller arteries their characteristic property respectively of elasticity and muscularity.

As the arteries branch out from the aorta they divide, the branches formed representing as we have seen a greater section area than they find in the larger trunk; hence the arterial sectional area increases from the aorta to the capillaries, becoming at the capillaries a very large region. The CAPILLARIES are vessels of microscopic minuteness, about 1-3000 of an inch in diameter. The capillary wall consists of a neucleated homogenous membrane continuous with the tunica adventitia. This membrane being lined by a single layer of endothelial cells, these cells being joined together at their borders or margins. These very minute capillaries are formed by division and by subdivision with almost uniform calibre, constituting net works or meshes, varying in different organs, being most minute in the lungs and the liver and larger in the case of the muscle. In these capillaries the blood current is slow, being more rapid at the center of the vessel. The delicate endothelial walls widen when the blood corpuscles pass, and narrow again when the pressure is removed. This thin wall admits of the passage of water, gas and even of corpuscles—particularly the white corpuscles—in the interchange that takes place between the blood and the tissues, through the medium of the lymph. The veins carry the blood back again from the capillaries to the heart. They have much thinner walls than the arteries and when cut across they collapse. The tunica intima in the veins is similar to and the tunica adventitia is identical with the arterial coats. The tunica media is different, consisting of white fibrous tissue with a few muscle-fibrous cells, and a little if any, elastic tissue. On account of this the veins, when empty collapse. These veins are very little elastic being simply channels through which the blood passes with only a certain amount of elasticity so as to be able to pass a certain quantity of blood necessary for the circulation. The sectional area of the veins like that of the arteries diminishes from the capillaries to the heart. The venous capacity is very much greater than the arterial capacity, the veins being able to hold all the blood normally found, both in the arteries and the veins. Inside most of the veins there are valves so arranged as to prevent the reflex current of the blood. Each of these valves consists of two flaps, projections of the inner coat placed on the opposite sides of the veins, and almost though not exactly, at the same level, so that the free margin of the one rests slightly, freely upon the free margin of the other. At the base each there is a small recess which assists the valve in supporting the column of blood above it. All of the large and middle sized vessels have within them very fine, delicate blood vessels in their walls, these blood vessels being found in the tunica adventitia. These blood vessels are supplied with nerve fibers distributed among the muscle fibers.

SECTION X.—Arterial System.

The walls of the arteries are both elastic and muscular. In the smaller arteries the muscular element and in the larger arteries the elastic element prevails. In the case of the large elastic arteries the blood enters with an intermittent flow from the heart, caused, of course, by the Ventricular beat being changed through the course of these larger arteries into a continuous flow before entering into the capillaries. At each contraction of the ventricle a volume of blood is thrown into the aorta which expands on all sides. When the ventricular diastole begins the aorta recoils the vis a tergo force, the force from behind being withdrawn ; the sigmoid valves being closed and the blood pushed along

the arterial circulation, the arteries expand as the blood flow increases and recoil as it diminishes. These movements of expansion and recoil are transmitted with diminished intensity as the blood flows from the heart. Two forces, therefore, are constantly acting in driving the blood along these vessels. The first force. the ventricular force of the systole, and 2d, the force that is produced by the elastic recoil of the vessel walls, taking place between the systoles of the ventricle. These two forces are constantly kept in regulation by the force of resistance within the vessels. As we have seen in the branching of the arteries, the cross section area is constantly increasing toward the periphery, and as the same quantity of blood is forced into the vessels at each systole, the expansion of the large vessels near the heart must be greater than the expansion of the smaller ones toward the periphery. The recoil following the expansion will also be greater, and the resistance increases as the vessels become less elastic, that is as we approach toward the periphery, because there is less yielding to the arteries ; they are more rigid and solid. This produces a gradually diminishing wave along the arterial blood path. As the arteries continue to branch this wave is reflexed somewhat, the resistance increasing with the diminution of the vessel bore.

The sudden flow of blood into the arteries is also accommodated by the short lengthening of the elastic arteries. At the bends or curves in the elastic arteries, the blood produces greater sinuosity, producing the twitching movement which can be observed more particularly in connection with the temporal arteries. This is sometimes confused with the pulse. It is not the pulse. It is what is sometimes called a secondary pulse. It is caused from the rapid turn in the blood. This wave gradually lessens from the heart to the capillaries. where it ceases altogether, the blood flowing continuously through the capillary circulation. As the blood circulates in this way through the arteries, there is transmitted along the arterial walls an undulatory series of movements consisting of successive expansions and recoils, constituting the arterial pulse. We say the arterial pulse, because later we will find a venous pulse—that is in certain conditions. Some Physiologists say there is no venous pulse, that there is only the one. That is not physiologically correct. The pulse represents not the blood flow in the vessels, but the transmission of undulatory movements along the arterial walls. These movements travel at the rate of eight to ten meters per second, in the upper and lower limbs more rapidly, being about 9.4 meters per second. This represents about thirty times the rapidity of the blood flow, the blood flow not being more than half a meter in the large arteries per second. and very much less in the smaller vessels. This rate of the pulse can be estimated by recording the movements at different points of the circulation, by the use of the sphygmograph. The pulse can be felt by the finger on the carotid artery, and later at the dorsal artery of the foot. The movement of the pulse or pulse wave is a progressive one. The transmission rate from the heart to the capillaries can be estimated almost exactly. This is done by estimating the time between the pulse beat at the origin of the aorta. and the same beat at the furthest artery; measuring the distance, approximately, at least, between these points. The time occupied by pulse in its transmission from the heart to the extremities is estimated at .2 or .3 of a second, corresponding with the ventricular systole. The pulse feeling is an artificial diagnostic sign in diseased conditions, the pulse being felt most generally at the radial artery on account of its nearness to the surface and from the fact that it is supported at that point by a bone foundation so that it is quite easily felt.

The pulse normally is characterized by regularity and by rhythm. Variation, however, may arise from disease or from some transient disturbance

causing an intermittent action, or by some irregularity. The pulse of high tension or an incompressible pulse, exists when an unusual amount of force is necessary in order to extinguish it. That, of course, means temporary. A pulse of low tension or a compressible one is one that may be easily extinguished. The high tension pulse marks a high blood pressure. A low tension pulse indicates a low blood pressure. These variations in pressure depend upon the action of the heart and the amount of perepheral resistance. A large pulse arises from the increase of the arterial calibre. If the pulse is very large it is called a bounding pulse. A small pulse, on the other hand, represents little if any increase in the calibre—the arterial calibre, and if the pulse is very small it is called a thready pulse. This does not mean largeness or smallness of the artery, but that the moving arterial pressure is large or small as compared, at least, with the mean blood pressure. As the blood moves along the artery the arterial pressure will be less according as the blood contents are less, and likewise the pressure upon the walls will be less when the walls give place more freely to the pressure. Hence a large pressure is often associated with a low mean pressure, and in this case it is foand, e. g., after severe hemorrhage—loss of blood. The pulse movements, as we have said, may be recorded by means of the sphygmograph. The best form of the sphygmograph is that invented by Marey. It consists of a long lever moving by a screw working on a small horizontal wheel; from the axis of which there is projected a light lever. The screw point rests on a flat disc at the end of an elastic spring, which presses the disc upon the artery. The lever arm records the tracing on a blackened surface carried in front of the lever point by means of a clock work arrangement.

In the sphygmograph, by modern adjustments of this instrument, the amount of pressure on the disc made by the artery can be closely and almost exactly preserved so that at different times tracings may be taken either with the same or different pressures. The best instrument is Marey's sphygmograph with pressure graduated arrangement by Mahomed and Bramwell. Various other instruments have been devised, e. g., the sphygmoscope, a small casket with membranous bottom to which is attached an inlet and outlet tube to convey the gas, the outlet being connected with a gas burner, the membrane being placed over the pulse, the flame will show the pulse beat. By the use of a silvered glass on the pulse a photograph may be obtained by the reflection of the pulse volume by clockwork on a dial. When the artery pulsates (1) it is expanded and shortly lengthened, and (2) the blood pressure rises—the artery giving rise to the resistance that is felt when the finger presses upon the artery. In connection with the sphymograph tracing we notice: 1. An ascending line, with the upstroke or the stroke of percussion, representing the arteral expansion resulting from the ventricular systole. 2. A descending line representing the arterial elastic recoil called the downstroke. In a normal pulse the expansion and recoil are successive without any rest, the pulsations being about equal. Variations take place, however, in the pulsations according to the blood pressure as it rises or falls. The quickness or slowness of the pulse is dependent upon the proportion of time occupied by these periods. If the time of arterial expansion diminishes, the pulse is rapid, if it increases the pulse is slow. The quickness of the pulse is increased by increased heart action, a free blood flow, proximity to the heart a and considerable yielding of the walls of the artery. The different parts represented on the pulse tracing are accounted for as follows: 1. The upstroke, which is quick, brief and steady, represents the ventricular systole, ~~the systole~~, the systolic wave, the opening of the semilunar valves and the rapid flow of blood from the ventricle

into the aorta and arteries, causing expansion of the arteries. 2. The downstroke represents the blood flow from the arteries to the capillaries and is prolonged, gradual and vibratory. 3. The large dicrotic wave on the downstroke represents the closure of the semilunar valves. 4. Following the upstroke or systolic wave during ventricular contraction we have the pre-dicrotic or second ventricular systolic wave represented in the curve tracing at the apex. 5. In some tracings where the pulse is irregular there are secondary waves arising from the elastic vibrations of the arterial walls. The vibrations of pressure are more or less constant. Sometimes the vibration becomes so irregular that it produces a partial upstroke of the pulse during the downstroke, causing a double beat during each ventricular beat. This is called a dicrotic pulse. The pulse is always dicrotic normally and hence the slight dicrotism gives origin to the name dicrotic wave. Much discussion has taken place as to the cause of this wave.

Much discussion has taken place among Physiologists, as to the origin or causes of this pulse wave. These opinions may be summarized under three heads :

1. Some Physiologists claim that there are two reflected secondary waves; one originating from the closure of the semilunar valves and another from the small arteries at the periphery starting backward, as a reflection of the main pulseway. This wave is supposed to be reflected backward from the periphery and travels toward the heart, reaching a given point in the arterial blood path after the main pulse wave has passed that point traveling in the opposite direction. If this is the case, then, in the tracing from the peripheral artery the dicrotic wave should arise nearer to the close of the upstroke, representing, therefore, the highest point that is reached by the pulsation, than in the case of an artery nearer to the heart. Measurements have shown that the difference between the primary and the secondary waves is greater in the smaller arteries than in the larger arteries nearer to the heart. This would prove that the dicrotic wave cannot be due to any secondary backward wave ; hence, this explanation is improbable.

2. The opinion that is supported by most of the Physiologists, is, that it is due to the slight rise of the arterial pressure arising from the closure of the sigmoid valves, and that this secondary wave follows after the main pulse wave from the opening into the aorta as a secondary wave. In this way the reflection takes place wholly from the heart, and it moves constantly toward the periphery, being modified in its course and giving rise to vibrations. This would make the closure of the aortic valve simultaneous with the beginning of the dicrotic wave. When the ventricular contraction takes place, a primary wave is transmitted along the arteries to the capillaries where it is destroyed. By the recoil of the walls of the aorta, the aortic valves close ; by the closure of these valves the secondary wave is reflected from the aorta to the periphery. It is this secondary reflected wave that produces the dicrotic expansion of the vessels, marking the dicrotic wave of the pulse tracing. The primary pulse wave passes gradually along the arteries from the heart. Similarly the dicrotic wave is marked farther down the curve, the farther the artery is from the heart. The wave becomes less marked as it travels farther from the origin—the origin in the aorta—hence, the wave becomes less distinct toward the periphery.

The dicrotic wave is more marked, as the primary wave is stronger, both of these depending on the strength of the ventricular systole. When the blood pressure of the small arteries becomes less, the dicrotic wave is greater as the wall of the vessels is able to yield more freely. The more full an artery is of

blood, there is less yielding in the vessel wall, and the dicrotic wave becomes less marked and more steady. Other secondary waves may also arise to render irregular the primary wave. Where there are three of these waves it is called tricrotic. Where there are many of these waves it is called polycrotic. If these secondary waves appear, only, in the down stroke, the curve is called katacrotic. Sometimes, however, one wave appears on the ascending part of the main curve, in which case it is called the anacrotic, associated in some way with irregular ventricular action, or a diseased condition of the ventricle.

3d. Foster explains the dicrotism without any reference to the closure of the semilunar valves. This closure, he says, is an effect, not the cause of the dicrotic wave. On the sudden cessation of the flow of the blood from the ventricles, a negative pressure is set up posterior to the blood, affecting the calibre of the vessels due to the vessels' elasticity, the result being that the vessel shrinks—particularly the vessel wall. This shrinkage becomes too great on account of the inertia of the walls, and there at once arises a secondary expansion, that is, you have an excessive shrinkage of the arterial wall, and when that excess shrinkage comes into contact with the inertia of the vessel wall, then there is produced this wave. This is assisted by the similar shrinkage and expansion of the blood. This gives rise to a series of successive waves, traveling from the root of the aorta along the arterial walls with gradually diminishing force, and produces the dicrotic wave. This dicrotic wave, thus produced, pulls after it the blood that has been, by reflex action, drawn back toward the heart and resulting in arterial expansion, and recoil according to the ventricular beats.

The sphygmograph cannot give a perfect tracing of the pulse, particularly the pressure line of the pulse, on account of the varying quantity of tissue lying between the surface of the skin and the arterial wall. On account of this the valve of the sphygmograph is relative, not absolute. The normal pulse rate in the male is about 72 per minute, and in the female from 78 to 80. This, however, is to be taken simp'y as an average, because in the healthy individual, it may vary all the way from 50 to 100. In the new born child it varies from 130 to 140, gradually diminishing till about the fifteenth year, when it ranges from 75 to 78. From sixty years of age it tends to rise gradually toward 80. The pulse is said, by some Physiologists, to be affected by the height of the body, being quicker, as they say, in the short body, in the longer body slower.

The pulse is affected by different bodily conditions, such as active exercise, a rise in the blood pressure, nervousness tending to raise the pulse. A rise of the temperature will also quicken the pulse. When the individual is lying down it is slower and when standing or walking it becomes faster. In the morning after rising it is slower, gradually rising to mid day, after which it decreases unless it is raised by active exercise or some other exciting cause. Toward evening it becomes slower, gradually becoming slower during sleep until about midnight, and after midnight it gradually becomes faster. The pulse beat affects more or less the entire bodily system, causing oscilations of the body which may be noted in some circumstances very distinctly. The pulse beats, also, visibly affect the teeth, nasal cavity, the larynx, the tympanum of the ear, and the eyes, producing certain movements in the internal parts of the eye and of the brain, especially manifest in the vibratory movements of the membrane at the junction of the cranial bones in the case of the child.

In the smaller arteries there is a considerable quantity of unstriped muscle which may produce contractile movements. These contractile movements are independent of the pulse and may be either temporary or permanent, but the ryth-

mical contraction usually results from the action of the nervous system on the blood circulation. This contraction, muscular contraction, affects, more or less, the arterial blood pressure, either assisting or hindering the blood flow and normally regulating the blood supply to the capillaries under the control of the arteries. These contractions in the different arteries supply the capillaries with a constant flow of blood, setting up what are called, a series of local circulations which balance each other, producing the natural blood flow to the different capillary regions.

In this way the circulation of the blood is maintained uniform, in the minute vessels of the brain, the minute vessels of the abdomen, of the liver and of the spleen, and especially the correlated circulation being regulated in such a way as to preserve a balace between the liver and spleen, the abdomen and lower parts of the body, the brain and thyroid glands. They are regulated so as preserve equilibrium. If the stethescope is placed over a large artery a sound may be heard; this sound being produced by the flow of the blood through the vessel under compression by the force of the stethescope. When the flow of blood passes beyond this pressure, the rapidity of the blood flow causes oscilations. These sounds are not produced by the oscilation of the arterial walls, although the elasticity of the arterial walls assisted by lessened peripheral resistance, aids the blood current, the blood passing away very freely and rapidly.

SECTION XI. Capillary Circulation.

The capillary circulation may be easily studied in connection with the frog's foot, the lung of the frog and any other of the organs in which fine capillaries are found. Each capillary of this minute network extending through the body constitutes a tube, the diameter of the finest of these tubes being from .005 to .020 part of a millimeter and extending in length from 1 to 5 mm. The number of these small capillaries depends upon the activity of the tissue, being more numerous in the active organs and active tissues. These minute vessels anastomose, forming network that vary in the different parts of the body. The circulation in the capillaries, small arteries and veins is continuous, there being normally no pulse, the intermittency of action arising in in the larger vessels on account of ventricular beat being overcome before the blood reaches the minute vessels. The walls of the minute vessels are very delicate, the calibre of the vessels varying so that in the lungs and among the muscle and nervous tissues where the blood performs its most important functions, the blood is collected in very minute vessels, moving slowly and over a very large surface. The capillary walls are composed of a very fine layer of endothelial cells, margin to margin closely joined together by cement matter. These delecate cellular walls become thicker we approach toward the small veins and arteries. This fine cellular character of the wall is of great importance physiologically in the interchanges taking place between the blood and the tissues The chief vital characteristic of the capillaries is contractibility upon which depends the elasticity and distension of the vessels in the modification of the calibre. On the application of stimulation the walls contract, the power of contraction residing in the endothelial cells lining these walls. This contraction is intimately connected with the variation of the blood supply, the vessels contracting or relaxing according to the requirements of the tissues. The existence and arrangement of these capillaries in the different tissues is such as to promote efficient functional activity. If the tissue or organ is very active the muscles of the body of the capillaries are arranged in long meshes, in the capillaries are very closely connected into a plexus; if the tissue organ is less active the arrangement is less minute and extensive. This arrangement is

always in harmony with the structure of the tissue or organs, e. g., in the connective tissue they assume irregular shapes, in the small cutaneous papillæ they form little circles. The capillary circulation is due to the heart force modified and modulated by the circulation through the vessels. Some physiologists consider that it is also influenced by the drawing action of a tissues through which the capillaries pass. This is proved by the increased amount of blood attracted to a tissue, that is very active, in order to sustain its nutrition, e. g. in the lactation of the mammary glands. This force represents the need of blood and may be considered as an active element along with the heart force in sustaining the circulation.

In the capillary circulation there is no pulse, the pulse movement transmitted along the arterial walls being extinguished mainly before the blood flow enters the capillaries, and finally, by the great resistance, arising from the minute subdivision of the capillaries. In the case of great distension in the smaller arteries and veins, there is a venous pulse. There may be, also, an abnormal capillary pulse. This is produced by the compression of the muscles in which the capillaries are situated, as for example, in the case of swellings due to inflammation in which a capillary pulse produces throbbing.

The current of blood varies in its rapidity, being more rapid in the smaller arteries than in the smaller veins. In the smallest capillaries the current seems to be almost uniform, at least in the vessels of the same size. This, however, is subject to variation even in the smallest vessels on account of the variation in the intensity of the heart beat. In the larger capillaries the red corpuscles travel with great rapidity along the center of the stream. Sometimes two or three of these red corpuscles travel abreast of each other while the white corpuscles move along the slower part of the stream close to the vessel walls. The red corpuscles, as we have said, move along the central part of the stream keeping separate, normally, from each other, unless in the case of their passing into the smaller capillaries, in which they move through the minute channels in single file, squeezing its bending and elastic substance through the narrow bore of the vessel, afterwards regaining their normal shape. The colorless corpuscles move chiefly in close contact with one another and with the vessel wall, moving much slower than the red corpuscles and adhering together, and closely adhering to the vessel wall even after the red corpuscles have squeezed themselves past the white corpuscles. This fact, that is, their moving less rapidly than the red corpuscles, close to the walls is due to their lighter specific gravity —that is, of the white corpuscles—the more dense corpuscles being driven out into the middle of the stream, the red corpuscles being slightly denser than the blood plasma, and the white corpuscles slightly less dense than the plasma. In addition to the density of the blood corpuscles the friction is always less at the middle of the stream than at the sides. This is evident from the fact that the white corpuscles along the sides of the stream are clearly separated from the red corpuscles in the middle of the stream by a narrow channel of blood plasma. In some cases the white corpuscles in addition to adhering to the vessel wall, passes through the vessel walls, this process of migration taking place between the minute cells of the endothelium lining of the walls. The leucocyte changes its shape very easily and thus, in its amoeboid movements passes through the vessel wall into the lymph.

This process may be seen in active operation under the microscope, by setting up an artificial inflammation in the mesentery of a frog by exposing it to the air for some time. In normal, healthy conditions it would seem that there exists a close relation between the vessel walls and the blood, according to which the adhesion of the corpuscles to the vessel walls is regulated, determin-

ing the normal flow of the blood along the side of the vessel. When inflammation is induced, the tendency to adhere is greatly increased, to such an extent as sometimes to stop the blood current, as the blood passes through the vessel. This may be increased to such an extent by the accumulation of these white corpuscles, and by the gradual lessening of the channel through which the blood passes until stagnation of the blood is produced, called stasis. In this case the red and the white corpuscles become mixed together in a mass, the two kinds of corpusles, red and white, passing through the vessel wall into the lymph spaces. In this case we have the condition, that we mentioned before in connection with the blood, diapedesis. In normal conditions the changes occurring in the vessel walls, assist the migration of these white corpuscles. The lymph that surrounds this area where the inflammation is set up being profuse with proteid matter. This would seem to indicate that the conditions of the tissues in which the vessel wall is located, promotes the circulation of the blood, particularly, the circulation of the white corpuscles in the blood. The speed of the blood varies from the wall toward the center of the vessel. The speed of the red corpuscles at the center of the stream is more rapid, therefore, than the speed of the white corpuscles, at the sides being markedly uniform through the course of the capillaries. The blood pressure within the capillaries is normally low, being liable to change, on account of the elasticity of the vessel wall causing normal changes of the vessel calibre. The lowness of the blood pressure is evident from the fact that on cutting the muscle, the blood trickles from the capillaries very slowly. This same result may be produced by compressing the skin until the cuticle becomes white and pallid on account of the expulsion of the blood out of the capillaries in the tissue. This pressure of the capillaries has been estimated by various Physiologists as ranging from 25 to 54 mm. In the pressure of the capillaries there is, also, an element which arises from the character of the blood. The resistance to the flow of blood seems to increase when the oxygen, carried by the red corpuscles, is diminished. In this way the blood and the vessel walls affect the pressure, and also the blood flow; the one influence molding and directing the other.

SECTION VII. The Venous Circulation.

The vein walls are thinner, more expansible and less elastic than the arterial walls As we said before, they contain fibrous muscular tissues and a little elastic tissue. The veins freely anastomose so that that there is a free circulation of the blood through the venous system. The venous blood circulation is dependent upon, (1) a suction action of the heart drawing the blood away from the veins toward the heart, (2) It depends upon muscular activity, acting upon veins in such a way as to press them while opening the venous valves toward the heart and thus aiding the blood flow in the direction of the heart. (3) It is aided by the diminished blood pressure in the veins as compared with the arteries and (4) It is also aided by respiratory action. This respiratory action assists the current of blood in its flow in the direction of the heart. In the case of the opening of a vein the blood flow is aided by muscular activity, producing in the case of the vein an even current of blood because of the absence of elasticity found in the veins as compared with the elasticity found in the arteries The force of gravity, also acts freely upon the blood flow. This is seen, for example, in the hanging downwards of the limbs, producing dilatation of the veins with the characteristic swollen appearance of the veins and the bluish color of the skin. This may be restored by lifting up the arm. When the limb is in this position the veins rapidly empty themselves; thus the flow of blood is much more free in the veins than it is in the arteries. The

only, or at least the chief check in the case of the veins is the action of the muscles which drive the blood in the direction of the heart; the valvular arrangement of the veins preventing any recurrent blood flow. The veins are found to possess no valves where the external pressure is absent, for example, in the brain and the internal portion of the bones. This valvular arrangement is of great value in connection with the vertical position of the body, as these valves prevent the blood from passing down to the lower extremities of the body, and also, promoting the circulation toward the heart. In addition to this the force of the blood presses the valves open toward the heart, at the same time preventing the blood from making its way backward to the peripheral extremities of the veins. In some cases we find the blood pressure is insufficient to carry off the blood into the circulation, the veins in such a case setting up a pulsation which has been called the secondary heart. Normally, as we said, there is no venous pulse, sometimes, however, the pulse wave passes on through the capillaries into the veins.

This pulse, as seen, for example, in the veins of the neck, is supposed to be produced by some obstacle that prevents the passage of the blood from the right auricle to the right ventricle. The pulse, in this case, is uniform in its time with the systole of the auricle. During the right ventricular systole the right auriculo-ventricular valve closes. Sometimes, however, this valve does not close sufficiently and as a result there is an undulatory movement transmitted along the wall of the superior vena cava to the veins of the neck, in this way producing the pulse of the venous circulation When the auricle and ventricle are in diastole the blood passes to the heart. This pulse arises from the imperfect activity of the jugular valve permitting the wave to pass along the jugular vein, causing the venous pulse of the neck. On the other hand, when the left auriculo-ventricular valve is weakened in some way, the right auricle becomes engorged with blood, and as a result a wave of contraction is transmitted to the veins. In the case of a tumor within the veins, there is sometimes produced such rigidity as to destroy elasticity and there is such an expansion of the capillaries that the wave which originates from the ventricular beat is transmitted through the capillaries to the veins. In connection with the salivary glands when the small arteries are dilated the blood may flow through these into the veins in a rapid and a pulsating stream, causing in these glands a venous pulse. When the heart begins to act feebly, for example, in old age, there may be or often is a very characteristic venous pulse, sometimes called the old age pulse.

SECTION XIII. Pulmonary and Portal Circulation.

In the pulmonary circulation the venous blood is returned by the veins to the right auricle, passing to the right ventricle on the contraction of the auricle, and on contraction of the ventricle, is passed along the pulmonary artery to the lungs in order to be cleansed. After having passed through the lung circuit it returns pure as arterial blood to the left auricle through the pulmonary vein. This pulmonary circulation, although essentially the same as the systemic circulation, differs in some particulars. The pulmonary circulation is small in extent, compared with the systemic. As the ventricles empty simultaneously and are of equal capacity, it is interesting to follow the circulation in the lungs. In the pulmonary circulation as compared with the systemic, the resistance is less, and therefore in the case of the ventricular contraction there is less resistance to be overcome by the right than by the left ventricle. The structure of the heart is such as to be prepared for this. The muscular wall of the left ventricle is very much thicker than that of the right. Hence the force of contraction in the case of

the right ventricle is very much less than that of the left ventricle. It is impossible to estimate the blood pressure or the rate of the blood flow in connection with the pulmonary circulation, because the pulmonary circulation cannot be reached unless after destroying the respiratory mechanism, and artificial respiration is not sufficient even if such artificial respiration could be produced to give a normal pulmonary circulation. The pulmonary artery, like the right ventricle as compared with the aorta and the left ventricle, has a very thin wall, indicating the lessening of the pressure.

The pulmonary artery conveying the venous blood from the heart is subdivided into a number of branches, the very minute vessels passing into the plexuses of the capillaries on the walls of the air vessels of the lungs. Arising out of these plexuses are the veins which collect the blood, pouring it into four larger veins, two for each lung, carrying it back by the pulmonary veins to the left auricle. The pressure of the pulmonary artery is much less than that in the aorta, the proportion being estimated about 2 to 5. The pulmonary system lies inside the thoracic cavity, although outside of the lungs, except in the case of the lung capillaries, hence, when the lungs are filled with air in inspiration the large vessels become expanded while the capillaries lining the surface of the lungs are subject to the same amount of pressure as the surface of the lungs upon which the entire air in the lungs may act. In this way the capillaries and the pulmonary veins are greatly assisted in freely circulating the blood, by this pressure, whereas, the pulmonary artery is weakened in its action. This, however, is counterbalanced to a large extent by the structure of the walls of the arteries as compared with the veins, the arteries being much more firm and solid. In this way the lung contraction in connection with the muscle of respiration materially aids the process of circulation in the pulmonary system, especially the activity of the right ventricle. The lungs expand on account of the internal pressure being greater than the external pressure in the pleural cavities. If this expansion is full in inspiration the elastic action exerted by them amounts to 30 mm of mercury. External to the lungs there is a pressure in the thoracic cavity bearing upon the surface of the heart and other organs equal to the pressure of the air minus the elastic force of the lungs, themselves, that is, 730 mm. The fine walls of the veins will yield to pressure easily during inspiration, lessening the pressure, while the thicker walls of the arteries will yield less, and in this way the blood flow from the lung capillaries to the heart is promoted. Expiration will have an opposite effect. The effect of inspiration upon the pulmonary capillaries and smaller vessels of the lungs is to assist the blood flow while expiration hinders it. This is due in inspiration to an increase of the calibre of the pulmonary vessels driving the blood to the lungs.

The blood rate of the pulmonary is greater than of the systemic circulation, and it is greater in the pulmonary veins than in the arteries. This is necessary in order to accommodate the same volume of blood in the pulmonary as in the systemic circulation. The right ventricle has sufficient force within itself to perform its work. This is evident from the fact that apart from the normal chest contraction, if the thoracic cavity be opened, the heart can perform its work without any respiratory action, if the respiration is preserved artificially. The pulmonary circulation, therefore, is much more simple than the systemic circulation.

Portal Circulation.

In the portal circulation there is one fact that requires particular notice, the passage of the blood through two capillary circulations in the abdomen and

the liver. The branches of the abdominal arteries carry the blood to the stomach, spleen, pancreas and the intestines, these branching off in the different organs in a series of capillary plexuses. Arising out of these plexuses are the veins joining together to form larger veins, the blood flowing through two veins, the splenic and mesenteric, into the portal vein through which it is passed to the liver, in which it is circulated by means of minutely branching capillaries collected into a plexus. Springing out of these plexuses in the liver lobules are the origins of the hepatic vein through which the blood is carried from the liver to the heart, by the inferior vena cava. If the portal vein is tied, all the abdominal vessels become expanded, causing congestion of the abdomen, producing rapid diminution of blood pressure and death. Sometimes the ventricular force produces a wave of contraction which is transmitted through the inferior vena cava and the liver, producing a liver pulse. In fact the liver normally follows the action of the heart in the inverse order contracting with each diastole, and distending with each systole of the heart.

SECTION XIV. Innervation of the Blood Vessels.

In the case of all the arteries it is found that muscular fibers are part of the lining of the vessel wall chiefly in the tunica media. This muscularity increases in the smaller arteries. The fibers of nerves are found largely distributed among the arteries, being collected around the muscular walls in small plexuses. If these nerve fibers are stimulated they respond by conveying the impulse along the muscular wall, producing contraction, resulting in the diminution of the vessel calibre. Similarly, the veins are muscular in their walls, although there is much greater variation among the veins. The nerves terminating in the muscle walls of the veins, also, convey impulses resulting in contraction of the vessel. This constriction and dilatation of the vessels is in the vessels themselves, under the control of the nerve fibers so that in all the arteries of the body there is a nervous influence imparted to the muscular walls from the nerves. These nerves are called the vaso-motor nerves. The muscularity of the walls may be represented as passing through three stages. 1st. Contraction of the muscle constricting the artery. 2d. Distension of the muscle dilating the artery. 3d. Moderate contraction of the muscle, in which case the artery is not greatly constricted or greatly dilated. This latter is called the tonic contraction or arterial tone representing the normal condition of many arteries for a long time. This subject was for a long time the vexed question in Physiology. It is not more than 50 years since the muscularity of the middle coat of the arteries was established. Henle first declared that "while the movement of the blood depends on the heart, its distribution depends on the blood vessels." It was known that the walls of these vessels were subject to contractility and that the nerves terminated in these muscular walls. From this it was taken as proved that the blood vessels were controlled by the nerves and that these nerves under stimulation influenced the contractility. It was discovered that by dividing the cervical sympathetic or extirpating the superior cervical ganglion the circulation was increased on the same side and the temperature raised. If the sympathetic is cut, in the neck there is dilatation of the vessels and a rise in the temperature. If the cephalic part of the nerve cut, be stimulated, it is found that the dilated vessels of the face soon begin to contract and the temperature falls, this contraction gradually increasing and soon passing away. On the withdrawal of the stimulus, the vessels again dilate. Therefore, it is concluded that there are nerve fibers in the sympathetic which influence the contractility of the vessels by constriction.

The spinal cord is found to originate certain fibres that produce the same

result. The submaxillary gland is well supplied with blood vessels, being supplied with nerves from the cervical sympathetic and from the chorda tympani, arising from the seventh cranial nerve and joining the lingual branch of the 5th nerve. After laying bare the submaxillary gland isolating the nerves into the gland, the vein was opened and the blood was found to be dark. The sympathetic branch was ligated after which the dark blood became as bright as scarlet. Stimulation was then applied to the nerve, between the gland and ligature, causing the blood to become dark again. Then the chorda tympani was ligatured and the end in connection with the gland stimulated, the blood flow-intermittently from the vein of a bright scarlet color. In the chorda tympania there must be, therefore, vaso-motor fibres producing the very opposite result from that noticed in the case of the stimulation of the cervical sympathetic; hence we come to the conclusion that there is a two-fold influence exercised upon the vessels as to size and quantity of blood in these vessels by the nerve fibres. Certain nerve fibres producing constriction of the vessels, vaso-constrictor nerves and certain nerve fibres producing dilatation of the vessels, vaso-dilator nerves In connection with the veins, the vaso motor influences are also apparent. If the aorta is subjected to pressure under the left subclavian artery, the portalvein ceases to receive blood from the intestinal arteries and still continues to hold a quantity of blood. If the splanchnic nerve is divided and the peripheral end stimulated, the portal vein contracts and drives out the blood into the capillaries of the liver. If the crural artery is ligatured and the sciatic nerve be divided, the application of stimulation to the peripheral end of the cut nerve produces contraction of the veins in the limbs; the contraction, if the stimulation is continued, entirely contracting the vessel so as to destroy its bore. Afterwards, withdrawing, stimulation the contraction disappears. The same principle is applied to the veins as to the arteries in connection with the vaso-motor nerves Nearly all the nerves of the body in this way are brought into play to influence in some way a part of the vascular area, the influence being either constrictor or dilator.

1. VASO-MOTOR FIBERS—There are two kinds of vaso-motor fibers, the vaso-dilator and the vaso-constrictor. These fibers originate in the central nervous system, the brain or the spinal cord. So far as the human subject is concerned, the vaso-constrictor fibers arise in the middle region of the spinal cord. or separate from the cerebro-spinal system by fibers which arise in this region. All the vaso-constrictor fibers seem to leave the spinal cord from the anterior roots of the spinal nerves, and after going through the branches of the viscera join the abdominal thoracic chains of the sympathetic ganglia. On entering these ganglia from the anterior roots and the visceral branches, they are medullated. After leaving these sympathetic ganglia, and before entering the blood vessels they become non-medullated, losing their medullated character in the ganglia. In the case of the vaso-dilator fibers, some of them run along side by side with the vaso-constrictor fibers; others, however, run in an independent course. In the case of the nerves of the cranial and sacral regions where no vaso-constrictor fibers are found, the vaso dilator fibers have been very distinctly followed. The dilator fibers for the submaxillary gland can be followed in the chorda tympani to the 7th nerve. Along the lingual nerve there are, also, dilator fibers to the tongue, as the application of stimulation to the lingual nerves produces dilatation of the blood vessels in the tongue. The eye and the nose receive dilator fibers from the trigeminal, and parotid gland from the ramus tympanicus of the glosso-pharyngeal nerve.

In the limb nerves the dilator fibers are less easily detected because of their junction with the vaso-constrictor fibers; although it is

thought by some Physiologists that the dilator fibers pass directly through the anterior spinal roots. In line with this idea it is stated by these Physiologists that the vaso-dilator fibers arise from all portions of the spinal cord as well as the medulla while the vaso-constrictor arise from a special portion of the cord passing indirectly through the splanchnic ganglia on their circuit to the different blood vessels, in connection with the body. The vaso-dilator fibers, also, differ from the vaso-constrictor fibers in retaining their medullated character until they are close to their terminal connection with the blood vessels. The vaso-constrictor fibers, at least, in the sympathetic, splanchnic and cutaneous nerves are constantly active, imparting a tonic constriction to the vessels, the division of these constrictor fibers resulting in the loss of arterial tone. The dilator fibers, on the other hand, are not in constant operation. The section of these fibers dces not produce any permanent effect, but simply a temporary dilatation, in all probability, due. to the irritation of the nerves by cutting rather than due to stimulation. These differences are most interesting from the fact that these two fibers are bound up in the same nerve, at least, as we said before, in a great number of cases these two fibers are bound up in the same nerve. It is only by these differences between the constrictor and dilator fibers that the fibers can be detected separately, otherwise, the action of the one fiber, might and would counteract the action of the other fiber. It seems to be more difficult to irritate the constrictor than the dilator fibers. If the constrictor and dilator fibers are stimulated at the same time and with an equal amount of stimulation in the submaxillary nerves the constrictor action prevails where as, after stimulation is withdrawn, dilatation will result.

The effect of heat and of cold upon the fibers is greater in the constrictor than in the dilator fibers, the heat increasing, and the cold diminishing the effect of contraction or of dilatation. A single induction shock affects slightly the constrictors, and very appreciably the dilator fibers, continuous shocks, on the other hand, affect the constrictor fibers very strongly; in some cases producing tetanus. If the two fibers are cut—the vaso dilator and the vaso-constrictor—away from their central origin, degeneration will set in more rapidly in the constrictor fibers than in the dilator fibers.

This vaso dilator action is most intimately connected with the blood circulation. As we have seen, before, the blood current in the system is regulated almost wholly by the tonic condition of the arteries. Normally, these minute arteries are in a tonic state of contraction, producing largely, the peripheral resistance, which is so important in connection with blood pressure, and also, with the blood flow. In addition to this general effect upon the circulation as a whole, we find also, that the circulation is affected in a separate local area, that is, vaso-motor changes, have both a general and a local influence upon the circulation. Arterial constriction in a local area results in lessening the flow of the blood through certain arteries, increasing the general arterial pressure, and causing the blood to flow more freely through the arterial channels: on the other hand, arterial dilatation results in increased blood flow through certain arteries, in lessening the general blood pressure, and in producing a lessened amount of blood in the other arteries. These effects vary as the local area affected by constriction or dilatation, is larger or smaller. In this way the central nervous system utilizes these vaso motor changes in order to govern the blood supply in the different parts of the body, influencing the blood supply, either in a general way, or in a particular way in a certain area, or part of the body.

2. Vaso-motor Centers.—These vaso-motor nerves, that we have spoken about, the constrictor and the dilator fibers, branch out, as we have seen, from

the sympathetic ganglia, these ganglia being subject to the influences of the spinal cord, whose ganglia, lying at different levels in the spinal cord, are under the control of the medullary centers. There are thus found to be three centers of vaso-motor influences. 1st. The great center, commonly called the vaso-motor center in the medulla, communicating by the intracranial and the intra-spinal nerves, with the second center, namely, the ganglia in the cerebro spinal axis, these ganglia representing the 2nd center communicating with the 3d center, namely, sympathetic ganglia by the spinal and the cranial nerves; these sympathetic ganglia sending out branches to the muscular walls of the vessels.

(a) The vaso-constrictor fibers have been found to arise from the middle portion of the spinal cord, passing into the sympathetic ganglia chain from which they pass by their branches to the superficial tissues of the body, the alimentary canal, the glands and their different appendages. If the spinal cord is divided in the lower dorsal region, and later in the upper dorsal region, noticeable effects are found to follow, for example after the division of the lower dorsal region the tonic influence is cut off from the lower extremities, causing the dilatation of the blood vessels, at the same time diminishing the peripheral resistance which is followed by a fall in the blood pressure. After the division of the upper dorsal region, the vessels of the abdomen, of the head and of the face become dilated and the blood pressure falls very markedly. This indicates that the tonic influences which affect the skin, the viscera and the lower extremities, emanates from some part of the central nervous system, above the upper dorsal portion of the spinal cord. The same results will be found to follow the division of the spinal cord close to the lower part of the medulla. If the cut fibers in any of these cases be stimulated, dilatation will give place to constriction. Hence the distension of the vessels of the trunk and limbs must have been caused by the interruption of vaso motor influences, the cutting off of these vaso-motor influences by the section, or the division of the spinal cord. If the whole of the brain be removed down to the upper parts of the medulla no distension and no fall in the blood pressure follows, or at least the fall is very slight. From these experiments it is concluded that there must be a vaso-motor center in the medulla oblongata located on the floor of the 4th ventricle, somewhere in the regional area of the calamus scriptorius and the corpora quadrigemina. Some experimenters have divided the bulb into sections, transverse sections, thus attempting to locate the center in a region at the lower border of the corpora quadrigemina lying in a bilateral position on both sides of the median line, said by some Physiologists, to correspond with the anterior nucleus of Clark. (b) There are also spinal centers in the spinal cord. Some experiments for example, in connection with the dog have shown us that by dividing the cord at the point of the junction between the dorsal and the lumbar portions of the spinal cord, thus dividing the animal body into two parts so as to sever the lumbar region from cerebral influence, these experimenters have found that the lower extremities of the body of the dog are warmer than the upper extremities, and the arteries of the lower extremities are more active than the arteries in the upper extremities.

This change in the blood must be due to the removal of the vaso-constrictor influences of the great vaso-motor center in the medulla. From this it is concluded that vaso motor centers must be found in the spinal cord. Reflex action takes place in connection with these centers. After the section of the spinal cord the at 3d vertebra, if the central end of the brachial nerves be stimulated, the vessels of the front limb are dilated. If the sciatic nerve be divided and then the central end be stimulated, the blood pressure will rise. This rise in

the blood pressure arises from constriction. If the sensory nerves in any limb be stimulated after the section of the spinal cord in the middle thoracic region then the vessels in the other limb will be constricted reflexly, indicating that reflex action takes place through these spinal centers; that are found in the spinal cord. (c.) In addition to these two centers we have also sympathetic centers. It is said by some Physiologists that even after the extirpation of the medullary centers and of the spinal centers there is still left a certain tonicity in the vascular mechanism. The lower part of the spinal cord has been completely removed. For some time after the removal, the lower extremities remain dilated, on account of the dilatation of the blood vessels. after distention of the blood vessels passes away, the limbs return to their normal condition, assuming tonic constriction altogether independent of the spinal cord. This proves that in connection with the sympathetic ganglia, there are centers. These centers are also the seat of reflex action, acting as the seat of other motor reflexes. If one of the branches of the annulus of Vieussens be divided and if the end still connected with the first thoracic ganglion be stimulated, after separating the branches connecting the ganglion with the spinal cord, contraction is apparent in the blood vessels of the ears and nose and submaxillary gland. This would seem to indicate that these sympathetic centers as well as the spinal centers ~~and~~ not simply subsidiary centers, but in a sense independent centers of vaso-motor action. In connection with some blood vessels certain rhythmical contractions are noticeable, these being entirely independent of the central nervous system. These are said to be seen in the median artery in the ear of a white rabbit and are said to originate in the emission of impulses from the vaso-motor centres. If the thoracic cavity be opened and the vagi divided, certain vibratory movements are noticed in connection with the blood pressure tracing. These vibrations are complicated and are probably due to variation in the respiratory center acting upon the vaso-motor centers through a process of irritation.

There is a certain relation between the cerebrum and the vaso-motor centers. By the application of stimulation to the cortex cerebri, and the other portions of the brain, it is found that the blood pressure is raised. This variation in the blood pressure is believed by some Physiologists to be the result of reflex actions, the cerebral centers originating impulses that are communicated to the vaso-motor. Afferent impulses originated in the blood vessels or in the terminal organs of the sensory fibers may excite the vaso-motor nerves reflexly. The limb of a rabbit was severed entirely from the trunk, leaving the sciatic nerve intact. The peripheral end of the crural artery was subjected to stimulation, that used in this case being the nitrate of silver. This stimulation was followed by an increase of blood pressure, and then after a few minutes by a fall in the blood pressure. This fall in the blood pressure being due to the stimulation conveyed by afferent nerves in the vessels and sent through the sciatic nerve to the vaso-motor center. Stimulation, therefore, of the sensory nerves produces reflexly constriction and dilatation. If food is placed in the mouth the nerves of taste originate certain influences producing efferent impulses in the centers, which pass out along the chorda tympani and other nerves to the salivary glands, resulting in the distension of the blood vessels, increasing the blood supply in these glands and exciting secretion. This may apply to the two sides of the body, as in the case of irritation of the mucous membrane on the one side of the nasal cavity producing a distension of the two sides of the head. The effect in this case is more noticeable on the side of stimulation. In the same way impulses may be transmitted along the vagus or along any of the sensory nerves to the center, producing

activity of the dilator fibers in chorda tympani or other nerves, resulting in an increased blood supply to the salivary glands. The muscular blood vessels, that is, the blood vessels that are deeply imbedded in the muscles, seem to be distended by vaso-motor influences; the dilator fibers being aroused to activity by the impulses that are conveyed along the motor nerves from the center in the spinal cord. This process, however, is complicated by the fact that when an afferent nerve is stimulated it will sometimes produce reflex dilatation and sometimes reflex constriction. This has been explained by different Physiologists in different ways. Some Physiologists think that it is due to variations taking place in the center, or centers, the result being dependent upon the condition of the center and also upon the time when the stimulation is communicated to the center, varying conditions of the center, therefore, producing varying results.

Other Physiologists, in more recent times. explain this fact more satisfactorily in connection with the pressor and the depressor fibers. The depressor fibers, as we saw, are dilator fibers, whereas the pressor fibers are constrictor nerves. We have already discussed the cardiac depressor which connects the heart with the center—the medulla producing on stimulation dilatation of the splanchnic, and other blood vessels, and a consequent fall in the blood pressure. It has been found that if a portion of the sciatic nerve is cooled by the application, for example, of ice, then by the application of a stimulation to the central end of this sciatic nerve, there is a fall in the blood pressure. If the sciatic nerve is divided, and before the regeneration of the nerve is completed, if stimulation is applied, there is dilatation produced, whereas, if the regeneration is completed, constriction follows, indicating the existence in the sciatic nerve of two kinds of fibers, the dilator and the constrictor fibers the depressor and the pressor fibers. If an animal is subjected to chloroform or ether, and the central end of the divided sciatic nerve be stimulated, the blood pressure rises without any corresponding increase in the action of the heart. After some time a fall in the blood pressure takes place, in some cases, even while the stimulation continues. Pressor fibers have been found in the laryngeal nerves, the trigenival nerve and the cervical sympathetic. This rise of pressure results from the constriction of the arteries in the abdominal region. It has been found that if the animal is placed under the influence of chloral, instead of chloroform, ether or curare, a fall in the blood pressure takes place instead of the rise. This seems to indicate that the result depends upon the center rather than entirely upon the nerve fibers; whether the action is accelerator or inhibitory. Thus the depressor nerve acts as an inhibitory, and the pressor nerve as an accelerator nerve fiber, in connection with the blood vessels conveying the afferent impulses of inhibition or acceleration to the center.

As we have seen, there are two kinds of vaso-motor fibers, the vaso-constrictor producing contraction of the vessels, and the vaso-dilator producing dilatation of the vessel. The question is asked in Physiology, "How does this action take place?" The only answer that Physiologists can give to this question would seem to be, that the fibers do not act directly upon the muscular walls of the vessels, and it is probable that the action takes place by an inhibitory action. In the vessel walls we find large numbers of ganglia. Out of these ganglia there pass nerve branches into the muscular walls. These local centers act, therefore, under the influence of the accelerator fibers and the inhibitory fibers.

Gaskell, on the other hand, thinks that these fibers exert a trophic influence, the constrictor fibers influencing Katabolism and the dilator fibers influencing the anabolism of the blood vessels. Blushing is a result of vaso-motor

action, certain emotions originate impulses in the brain which powerfully inhibit the vaso-motor center, governing the vascular region of the head, governed by the cervical sympathetic. The relaxation of the muscular walls of the vessels results, the arteries being distended and suffusion taking place. Sometimes pallor—the paleness of the skin, is also produced in the reverse way, that is, pallor is sometimes also the result of vaso-motor action. It results from the constriction of the arteries through the cervical sympathetic and the vaso motor center. The blood pressure is also influenced by respiratory action. Inspiration takes away the pressure from the external surface of the vessels allowing the large veins and arteries to expand; as the veins are more expansible during inspiration, the blood tends to collect in these large veins next the heart, causing, therefore, a fall of blood pressure in the aorta. In expiration, on the other hand, the reverse of this process takes place, the blood pressure being increased at the aorta. This, however, is not strictly scientific, because, during inspiration there are two moments or stages. During the first stage the blood pressure falls. During the second stage the blood pressure rises. This is due in part, at leaft, to vaso-motor action. During the second part, of inspiration certain influences are sent from the center, causing the contraction of the small vessels and producing a rise in the blood pressure in the arteries. During the 1st part of inspiration the cardio-inhibitory center acts, and the heart, as a result, beats more slowly. Thus, the vaso-motor influence, acts upon the blood vessel in connection with respiration, Some attempts have been made to specify and localize all the nerves in connection with the different regions of the body. This, however, is topographic rather than physiological and therefore, belongs to the field, not of Physiology, but of Anatomy.

SECTION XV—III. Branch of the Circulation. General Circulation, Its Mechanism, Including the Circulation of the Blood and the Circulation of the Lymph.

PRESSURE:—We have studied specially the organs of circulation and their Physiological bearing. There are still some points left that belong to circulation, not specially, but in general. The circulatory system, as we have said, may be ideally considered as a tubular arrangement. If the blood is regularly distributed under the same pressure, there will be an equilibrum in the circulation, and circulation would be impossible. When the pressure varies at any point, as in the case of the ventricular contraction the blood will be thrown out of that place with greater pressure to the part in the circulation with the lower pressure, and hence the circulation will be normally promoted.

If the heart action, on the other hand, is arrested, then the pressure is diminished. This diminution takes place gradually until the blood ceases altogether to circulate. Thus, beginning with the heart in its opening into the aorta, we have the point of the greatest pressure, the pressure gradually diminishing along the arterial system, the capillary system and the venous system until we come back again to the heart. Consequently the blood flow is from the heart through the arteries, capillaries and veins to the heart again. Each heart beat ejects as much blood into the arteries as returns into the heart from the veins and as the opening into the heart from the veins are more subject to dilatation than the openings of the arteries, the pressure in the arteries increases.

Artificial arrangements have been made by some Physiologists, as Weber and Hering, called the schema of circulation, consisting of a main pump representing the heartwith tubular attachments to represent the arteries and veins. It can be easilyshown in this way that if the pressure in the arteries and veins is equal, there can be no circulation, and also it has been proved that by increasing

the arterial pressure, the circulation is efficiently promoted through the whole circuit of the tube. Thus the circulation of the blood as a whole depends upon two facts: 1. The strength and rhythm of the heart beat. 2. The resistance that is set up in the capillaries which we have called peripheral resistance. This peripheral resistance increases the arterial blood pressure, and thus, as you notice, from the increase of the arterial blood pressure there is a new force added onto the force in the heart, driving the blood out of the arteries toward the capillaries into the veins, thus promoting the circulation of the blood out of the arteries toward the capillaries into the veins, thus promoting the circulation of the blood. The main force in the circulation is the heart. Under this influence the blood circulates through the vessels, exerting a constant influence in the form of pressure at every point along the line of circulation, this pressure varying at the different points, being high in the arteries, greatly diminished toward the capillaries and being low when it reaches the veins, the blood flowing continuously from the high pressure to the low pressure through the capillaries which represent medium pressure.

If an artery, e. g., the carotid is ligatured in two places so as to leave an isolated portion, that isolated part can be divided, and a long canula open at the two ends can be fixed into the proximal end of the artery. If the ligature be removed and the canula be held upright the blood will rise to a certain height and remain there. If a vein, e. g., the jugular, be ligatured and then divided, and a tube be inserted in the distal portion, on removing the ligature the blood will rise in the tube but only a short height. This has been estimated in the case of the dog as varying from 155 centimeters in the aorta to 18 centimeters in the veins of the head, representing a variation in pressure of 8 or 9 : 1 in the case of the arteries and veins. In connection with this rough experiment we notice that the arterial blood is constantly moving up and down, the variation representing 1 or 2 centimeters, corresponding almost identically with the frequency of the breathing, whereas the smaller variations in the surface correspond with the heart-beat. On the other hand the venous blood is almost perfectly still and steady. From this we conclude that the arterial pressure varies with the respiratory movements of the chest and with the contractions and relaxations of the ventricles of the heart, producing the continuous movement of the blood through the capillaries; whereas the venous pressure is steady and maintains the even blood flow toward the heart. The first application of this arrangement to the arterial and venous blood pressure was by Hales in 1727. He took a long tube nine feet and one-fourth of an inch in diameter, provided with a stopcock connecting the tube with the crural artery of a horse, admitting the blood into the tube, and watching the vibrations of the blood in the tube at each heart-beat, the pressure being measured by the column of blood and the variations of pressure by the vibrations of the blood in the tube. This method, however, is unsatisfactory on account of the length of the tube required and the readiness of the blood to coagulate. In 1828 Poisenille devised the bent tube in the U shape and put mercury in the bend, a substance heavier and more movable than the blood. He also used means to prevent the clotting of the blood, securing a convenient arrangement for observation and measurement. This instrument was called Hæmadynamometer. The modern mercurial manometer is an improved form of this instrument. It consists of a glass tube bent in V shape, open at the two ends, held in position by a metallic frame-work. Mercury is placed in the vessel so as to occupy the bend. The one end fitted into the blood vessel is capped with a stop-cock. Before the blood is passed into the tube a solution is passed into the tube to prevent the blood from coagulating, e. g., carbonate of soda or

magnesium sulphate. On account of the cardiac and respiratory changes this method was unsatisfactory, because the pressure could not be accurately read. Ludwig invented his self-registering manometer to get over this. He placed upon the mercurial surface in the distal limb, a small ivory float, bearing a light marking rod. Any change in the mercury caused the marker to rise or fall, with an arrangement for marking the change, by means of which cardiac and respiratory changes are graphically represented in carved lines upon a moving surface of the kymograph. The pressure represented upon this instrument is the mean blood pressure. Various attempts have been made to register the slighter changes by means of the spring kymograph which possesses the advantage of delicacy and accuracy. These instruments are valuable as showing the variations in individual beats with the changes in vibrations.

To secure a blood pressure tracing, an artery is laid open in an animal subjected to chloral. Thereafter two ligatures are applied so as to isolate a part. An incision is made into the artery, and a tube inserted in the vessel next the heart. The tube is filled with anti-coagulation solution, and connected by a rubber tube with the short limb of the manometer. The ligature is then taken off and the blood flows, acting upon the solution, and the mercury in the manometer pushing up the float which vibrates, and then records its movements. To discover the intra-vascular pressure at any moment, we must measure the height of the ordinate, a vertical line drawn from the curve recorded by the manometer to the abscissa, or horizontal base line, this latter representing the height of the column of mercury, under the influence of the atmosphere and the solution of carbonate. This number must be doubled in order to represent the actual blood pressure, because the mercury in the proximal limb sinks just the length the mercury rises in the distal limb. This enables us to represent the blood pressure in millimeters of mercury, varying in the different arteries and veins. If the canula be inserted in the large veins of the neck at the entrance into the thoracic cavity, there will be found a negative pressure representing a friction action from the inside of the vein. These facts indicate that blood pressure is, as we stated, dependent upon purely physical laws, being simply a movement of the blood within the tubular system, from a tube in which there is a high pressure to tubes of lower pressure. If the blood vessels are injured or cut, certain phenomena are noticed, e. g., in the case of an artery, the high pressure causes the blood to flow out like a jet, whereas, from a wounded vein the blood flows steady without any pulsation. This represents roughly the variation in pressure found in the arteries and veins.

From such experiments as these, certain conclusions have been reached in regard to the blood pressure. That conclusion varies in the case of arterial pressure, the capillary pressure and the venous pressure. (1) The arterial pressure. The arterial system, as we have seen, gradually increases its cross section area by the multiplication through division or sub-division of the minute vessels. This division and sub-division mark the transition from the minute arteries to the capillaries. Arising from this minute sub division there is a strong force of resistance transmitted backwards according to the physical laws of fluid pressure, through the capillaries, through the minute arteries, and through the larger arteries toward the heart. This resistance originates in the capillaries, presenting a very strong resistance to the blood flow from the heart. This resistance is greatest, of course, in the capillaries and in the smaller vessels, gradually diminishing backward along the blood path until we reach the heart. This resistant force, therefore, meets the great force of the heart.

At the aortic opening into the heart the ventricular force throwing open the valve, drives out the blood from the ventricle into the arterial system with

an intermittent stream, this ventricular force meeting and over bearing the peripheral resistance that is sent up from the capillaries. The great pressure, therefore, in the arterial system is due to the interaction of the great force of the heart and the resistance that is sent up from the periphery. This high pressure in the arterial system maintains its uniformity, chiefly on account of the elasticity of the arterial walls. At each heart beat there is ejected from the heart into the arterial system a certain volume of blood. This volume of blood has to meet the resistance from the capillaries. This must be compensated for, by the discharge of blood from the arteries into the capillaries, and at the same time the distension of the arterial walls, so as to provide for an accommodation of the volume of blood. As these successive blood ejections take place the aeterial walls yield before the peripheral resistance, the blood remaining in the arterial system, and thus increasing the blood pressure. This goes on until the limit is reached. At this point the walls are fully distended; they become hard and stiff. As a result of this the blood pressure is very high, and the successive blood ejections from the heart cause the pushing backward of the blood into the capillaries. Thus the normal condition of arterial pressure would represent the discharge of blood from the arteries during the ventricular diastole into the capillaries equal in volume to the amount of blood thrown out of the heart into the arteries at each ventricular beat. During each systole of the heart, the muscle of the heart actively performs a certain amount of work in producing a force to expand the arterial walls, for the purpose of accomodating the blood driven from the heart into these arteries and also assisting to sustain the capillary blood flow against the peripheral resistance. The force thus generated by the muscular activity of the heart is divided between the elastic arterial fibers in expansion and the capillaries which receive the blood supply from the arteries during the arterial recoil when the heart and the heart muscles are resting. At the commencement of the diastole the arterial recoil closes the arterial valves. During the systole of the heart, on the other hand, the arterial walls are expanded before the volume of blood that is thrown into the arteries from the heart, and in this way the pressure of the blood is raised on account of the increase in the volume of blood.

During diastole the arterial walls recoil and the blood pressure falls on account of the increased quantity of blood thrown out of the arteries into the capillaries Before this fall in the blood pressure becomes low, the systole of the heart or of the ventricles rather, takes place and the blood is again driven out of the ventricle into the aorta, raising, once more, the blood pressure. these different stages go on successively, preserving, in this way, the mean blood pressure that is normally found in connection with the arterial system. The arterial blood pressure is caused: 1st of all, by the blood driven out of the heart on the contraction of the ventricle. 2. By the resistance that is met with in the minute vessels, known as the peripheral resistance; and 3. By the elasticity of the arterial walls. These are three causes of the arterial blood pressure. Thus the pressure of the blood is lessened gradually from the heart to the capillaries. It reaches its highest point in the case of the ventricle during systole, and its lowest point in the auricle during diastole, during which, as we will find, there is often found a negative pressure in connection with the large veins and the auricles.

The arterial blood pressure varies, rising at the moment of the ventricular systole and falling at the moment of diastole, these variations being greater at the points nearer the heart. The mean pressure of the whole arterial system is to be distinguished from the mean blood pressure at any one point along the arterial blood path. The mean blood pressure of the arterial system

is estimated by calculating the mean pressure at the different points along the arterial system and then striking an average between these different mean pressures. This mean blood pressure of the arterial system varies with the volume of blood found in the arterial system, for example; in plethora and in the case of transfusion, consequently lessening of the total arterial calibre will raise the mean blood pressure. The mean blood pressure increases with the force of the ventricular beat, so that the acceleration of the heart's action increases the mean blood pressure. If, on the other hand, the action of the heart is weakened, as in an anæmic condition, and in the case of the loss of blood by hemorrhage, of the mean blood pressure is lessened. In certain abnormal conditions, for example, in the case of fever, and in the case of hemorrhage and in phthisis, the pressure of the blood in the arterial system is always lessened; while in the case of lead poisoning, for example, or in the case of the injection of ergot and digitalis into the blood, or in the case of the induration in the arterial walls and in case of the abnormal enlargement of the heart there is an increase in the blood pressure, at least, in the arterial system.

2 CAPILLARY BLOOD PRESSURE.—In connection with the capillary blood flow, we have seen that it is uniform and free from rhythmic changes. The pressure, therefore, of the capillary system is low, as compared with the arterial system. As we have seen, the force that drives the blood into, and through the capillaries, is the force of the heart imparted to the arterial walls, manifested in the recoil or contraction of the arterial walls, following distension. While the heart is resting, the arterial walls recoil, the work being carried on by the force transmitted from the heart at the preceding systole. This force is to meet with, and overcome the capillary resistance. Thus the forces which produce the capillary circulation are, 1st of all, the heart force. 2nd. The elastic force of the arterial walls, and 3rd The peripheral resistance. The blood that flows intermittently from the heart on its entrance into the capillaries loses its pulsation, and also its high pressure. There is much less resistance to be overcome in the passage of the blood from the capillaries into the veins, than in the case of the entrance of the blood from the minute arteries into the capillaries. This resistance is constantly diminishing through the course of the capillary circulation. The force of the heart beat is also greatly lessened, much of the energy having passed into heat, and this heat having been exhausted in preserving the arterial blood pressure. Thus, a lessened force meeting with a lessened resistance, is what we find in the capillary circulation. The blood flow is, therefore, slow and steady, and the pressure is also low all through the capillary system. At the arterial recoil, as we saw before, there is a volume of blood thrown into the capillaries during the ventricular diastole, equal to the volume of blood displaced during the ventricular systole. In this way the arterial pulse, and changes due to cease respiratory influences altogether at, or about, the close of the arterial system, leaving the blood in a constant stream to issue through the capillaries, supplying the tissues; and then returning to the veins. Any condition that favors or assists the blood flow to a capillary region, will raise the capillary pressure; for example, distension of the small arteries opening into the capillaries, contraction of the small veins on the other hand, leading away from the capillaries, will have the same effect, increasing the blood pressure, preventing the volume of blood passing away from the capillaries into the veins. The position of the capillaries and their arrangement in that peculiar net work among the muscular fibers together with compression, or contraction of the muscles bearing upon the capillaries, will influence the capillary pressure.

3 VENOUS BLOOD PRESSURE:—The venous blood pressure is lower in the min-

ute veins than in the capillaries, gradually diminishing, as we saw, toward the heart. In the larger veins at or near the heart the pressure ranges from a slight positive to a slight negative. This negative pressure depends largely upon respiratory action. This diminishing blood pressure in the veins arises from the same causes as the low blood pressure in the capillaries. It is the heart force transmitted along the arterial walls and through the capillaries, that forces the blood into the veins. There is still, as we have said, a certain amount of resistance in the venous circulation, although the resistance is gradually lessening all the way toward the heart. The elasticity of the walls of the veins is very slight, and hence the blood moves freely along the venous blood path with no greater internal pressure than the external atmospheric pressure. While the heart force is sufficient to drive the blood through the veins, there are certain forces which assist the blood through the venous circulation toward the heart. These forces are three in number. 1st of all, the aid rendered by the lungs in the venous circulation. 2d. The force of the muscles of inspiration, and third, the force that arises from the skeletal muscles. (1) The lungs exert an influence upon the venous circulation. During inspiration and expiration, the two stages of respiration, the lungs are stretched, the lung fibers drawing on the ribs, the diaphragm, the heart and the other organs in the thoracic cavity. This distending force acts upon the heart during the ventricular diastole. This same drawing force generates in the superior and inferior vena cava suction force which affects the venous circulation. This suction action tends to draw blood without the thoracic cavity inside the chest. As we have seen there is a negative pressure always found in the veins close to the chest, this negative pressure giving place to a positive pressure farther away from the chest in the venous blood path. Thus the elastic traction of the lungs is constantly exerting a drawing influence upon the venous blood toward the heart. (2) This force of aspiration in connection with the lungs is materially aided by the muscles of inspiration which by their contractions strengthen the traction force of the lungs. At each dilatation of the chest there is a force generated which sucks the blood into the chest cavity, when contraction takes place this force is suspended so that the muscular force which draws upon the venous circulation is not constant but is marked by the successive inspirations.

(3) There is an influence exerted temporarily by the skeletal muscles. When these muscles contract, compression is brought to bear upon the veins in close proximity to these muscles, so that the blood, by this compression, is driven out of the veins, and the venous blood pressure is overcome. Here the valvular arrangement of the veins, together with the free anastomosis of the veins, prevents the blood from being driven away from the heart and causes the blood, always, to pass in the direction of the heart. Thus muscular compression may temporarily assist in promoting the venous circulation. This is not constant, but only temporary, because if the compression is continued for a length of time it would result in the destruction of the vein, or the obstruction of the circulation, not by causing the blood to pass away from the heart, but by destroying the vein, or veins in this region. The diminution in the blood pressure is so great that in the large veins near to the heart it is estimated that the pressure is only about one-twentieth part of the pressure in the arteries next to the heart. There are no great variations in the venous blood pressure, unless in those large veins close to the heart in which the pressure increases during the auricular contraction and diminishes during the auricular expansion. Great activity in the heart produces a lessened pressure, all through the venous circulation. Anæmic blood conditions for example, produce a diminution

of the venous blood pressure. Plethoric blood conditions produce an increase in the venous blood pressure ; changes, also, in the normal position of the limbs affect the venous circulation. For example, the raising of the extremities promotes the venous circulation toward the heart. The downward inclination on the other hand, of the head, retards the venous circulation toward the heart. In the case of deep breathing, the traction force of the lungs increases the negative pressure in the veins close to the heart. This negative pressure increasing backwards along the blood path at each deep inspiration. When the chest relaxes, the pressure is raised, causing the venous pulsations, which are simultaneous with the respirations At every inspiration the blood is being sucked out of the veins and the veins diminish in size. During expiration, on the other hand, the veins increase in size on account of the volume of blood from the smaller veins. In close proximity to the chest there is always, therefore, a negative pressure. In very deep inspiration this negative pressure may be extended so far along the neck and the arms as to reach what is called "the point of danger."

This point of danger is so called because of the danger that arises in the case of the wounding of the vein, or its being cut in some way, resulting in the sucking of air into the veins, and its passage along with the blood into the heart which may result in sudden death, from the sudden entrance of the blood and the air into the heart. This danger point is so called by surgeons because of danger associated with operations in this region. Various attempts have been made to estimate the blood pressure at the different points along the blood path. This, however, varies so much in the different individuals, and in the different conditions of the same individual that no importance can be attached to the estimated results. It is to be noticed, however, that ⅓ of the blood may be taken out of the system without any effect upon the blood pressure. It is estimated that 2-5 of the blood withdrawn, will slightly lower the blood pressure, a considerable fall being noticed in connection with the removal of ½ of the blood. If ¾ of the blood volume is removed, the pressure gradually falls until the heart ceases altogether to act. In the case of the depleted blood, the transfusion of a .75 per cent solution of sodium choloride will raise the blood pressure, and tend to restore the normal condition of the blood.

SECTION XVI.—Velocity of the Blood Circulation.

The speed of the blood is of considerable importance. Various instruments have been invented in order to discover what this speed is. If an artery is cut the blood issues from the artery with great velocity. The blood moves along the blood path with considerable speed, gradually diminishing from the heart along the arteries and through the capillaries and the veins. The measurements, however, are only approximate, and they cannot be taken as indicating the real, or accurate velocity of the blood. In the larger veins and arteries the measurement cannot be made directly. If it were possible to measure accurately the vessel calibre, and also the volume of blood that passes through it in any given time, then it would be a simple arithmetical circulation to determine the blood speed. This, however, is difficult to determine, chiefly because of the varying calibre of the vessels, and the varying resistance that the blood meets with in the blood flow. The Hæmadromometer of Volkmann consists of a V shaped glass tube, with stop corks and metal attachments. The blood was then allowed to pass through the tube, and as the length of the tube was known the time of making, the circuit of the tube could be easily noticed. The velocity in this case, is retarded by the artificial glass nature of the tube, and hence, the measurement is not even approximate. The best instrument that

has been invented is the stromuhr, or rheometer of Ludwig. This stromuhr consists of two glass bulbs, equal in capacity, connected together at the top by a common tube. At the bottom ends of the bulbs there are two tubes with two smaller canulæ at the end, for insertion into the ends of the vessels. The two bulbs are fixed upon two metal discs, these two discs being turned on the top of two other discs, on which they can rotate so that each bulb can be moved around, so as to be brought into connection with the two lower tubes in succession. The one bulb is filled with oil, and the other bulb with defibrinated blood.

An artery is then divided and the two canulæ are connected with the two ends of the divided artery. The blood rushes out of the artery through the canula into the bulb, throwing out the oil into the other bulb while the defibrinated blood is pushed by the oil out of the other bulb into the other end of the artery. The time is noticed during which the one bulb filled with oil is filled with blood the other being filled with oil at the same time. This represents the time in which the volume of blood equal to the size of the bulb passes through the artery. From this estimate, the velocity of the blood can be estimated. The experiment is continued by reversing the bulbs. In the experiment of Ludwig the bulb was able to hold five cubic centimeters. From the time of allowing the first five cubic centimeters of blood to enter into the tube until the moment when the last five cubic centimeters escapes from the artery into the tube, one hundred seconds elapsed, during which time five cubic centimeters of blood was received ten times into the tube from the arteries, all the blood, except the last five cubic centimeters of blood, being returned again at the other end of the artery into the circulation. Thus in one second five cubic centimeters of blood has flowed. Estimating the size of the canula he found that 159 m. m. of blood flowed in one second. In this way he estimated the amount of blood flowing in a given time and also the speed of the blood. This point is of considerable importance in the Physiology of circulation, because it enables us to calculate, at least approximately the duration of the circulation. One difficulty in this case, is that the stromuhr only gives the velocity of the blood during the experiment. In rapid changes of the velocity, another method has been used to determine the normal blood velocity. Vierordt, a German Physiologist, constructed the Haematachometer, in order to estimate the velocity by observing deviation. This instrument consists of a small metal box with parallel glass sides with a canula at each side, these two being connected, as before, to the ends of the divided artery. Inside the box there is suspended from the top a pendulum; the vibrations of this pendulum can be read on a graduated scale. When the blood is cut off from the instrument the pendulum hangs vertical, when the blood is permitted to flow through the canula and through the chamber, the pendulum is deflected. The velocity can be estimated from this deflection because the graduation upon the scale is based upon the speed of a fluid where velocity is known. It has been found that the velocity of the blood is subject to great variation. In the different arteries the velocity, for example, in the case of the carotid artery of the dog, is found to be 205 to 350 mm per second, in the crural artery of the dog 140 to 240 mm per second. Chauveau, who conducted a great number of experiments, found in the large arteries close to the heart during systole there was a velocity of 520 mm per second, whereas during diastole the velocity was 220 mm per second, and during rest 150 mm per second. The arterial velocity diminishes toward the capillaries from the heart.

The capillary velocity cannot be measured directly by any of these instruments. It can be measured, however, by the use of the micrometer used

in connection with the microscope. Some Physiologists have measured the speed of the blood in the capillaries of the retina in their own eyes. It is found that the velocity in the case of the capillaries is very much less than the in case of the arteries. Weber estimates the velocity in the case of the web of the frog's foot at 51-100 mm. per second, and in the case of the mammalian capillaries, 8-10 mm. per second. Other Physiologists estimate that in the human subject there is a normal capillary velocity varying from 6-10 to 9-10 mm. per second. Volkmann states that in the human subject the veloc y of the blood in the aorta is 600 times the velocity of the blood in the capillaries, and the velocity of the minute arteries is 10 times the velocity of the capillaries. In the case of the veins the velocity is small in the minute veins leaving the capillaries, increasing gradually as the veins become larger, until in the larger veins close to the heart it is found to be from 200 to 225 mm. per second, for example, in the jugular vein of the dog and also of a horse; these are estimated 200 to 235 mm. per second. The venous velocity increases, therefore, from the capillaries to the heart. This acceleration in the venous velocity is due partly to the diminished resistance. Comparing the velocity of the blood with the blood pressure, there are certain conditions that we find to be noted. In the case of the arteries, the velocity and accompany each other, both in rising and in falling, both the velocity and the blood pressure gradually diminishing from the heart to the capillaries. In the capillaries the velocity and the blood pressure are low. In the veins, on the other hand, there is a low blood pressure, diminishing gradually all along the venous path, whereas, the speed is higher than we have had it in the capillaries, and it increases all the way toward the heart. There is no relation, therefore, between the velocity of the blood and the blood pressure, being in direct relation to one another in the case of the arteries and in the capillaries, and inverse in relation to one another throughout the venous blood path. The velocity in the capillaries is very slow, compared, at least, with the large veins and with the large arteries, whereas, the minute veins and the minute arteries have a greater velocity than that we find in the capillaries. This fact is of great physiological value, because in the capillaries the great function of supplying the tissues is performed, a certain volume of blood being required to do this, and that the blood must pass slowly in order to permit the blood entering into the tissues and to allow the blood interexchange.

The circulation of the blood requires that an equal volume of blood must pass any two points in the circulation, in equal periods of time except in cases of abnormal disturbance. This, of course, does not mean that the rate requires to be uniform in all the arteries, capillaries and veins, because the rapidity in one is compensated for a lower rate in the others. This is easily explained because the large arteries and veins are few in number and small in their cross-section area as compared with the small vessels and the minute capillaries. The cross-sectional area increases with the subdivision of the vessels. This sectional area, therefore, is gradually increasing from the heart to the capillaries; hence, the smaller the blood vessels, the larger is the blood path at that region, the widest path being in the most minute capillaries. Vierordt, a German Physiologist, states that the cross-section area of the capillaries is eight hundred times that of the arteries at the root of the aorta, and four hundred times that of the veins at the venous orifices. Thus the venous circulation is much greater in calibre, than the arterial system. The arterial and the venous cones lie with their narrow ends toward the heart, connected together at the two bases by the capillaries. An equal volume of blood passes in the same, or equal periods of time, any two points

in the blood path, so that in the narrow path the blood must flow very rapidly, and, in the wider path, more slowly. The velocity, therefore, diminishes on account of the widening of the blood path toward the capillaries, causing the velocity to be lowest in these capillaries where the blood path is the widest. In the venous blood path, the gradual narrowing of the path toward heart causes the increase of the speed, and the fall in blood pressure, the speed being so much lower in the venous system, because the venous blood path is so much larger than the arterial blood path. The blood flows, therefore, much more slowly into the right auricle. than it moves out of the left ventricle, because the path is wider, although the volume is about the same. The reason of this is, the calibre is very much larger at the venous orifices. This corresponds with what we have found in connection with the heart, that the blood pours in during the long auricular diastole, and leaves during the short ventricular systole. It is found, therefore, from this standpoint, that the velocity of the blood flow depends upon the width of the path, being greatest at the aorta, diminishing toward the capillaries and then increasing again toward the heart in the venous system. Resistance in the capillaries plays only a very small part in determining the velocity, at least in the capillaries, but the increased sectional area is the element which determines the velocity all the way around the blood path. The ventricular force produces the blood flow through the entire circulation, genating the force of the arterial walls, and thus producing a force sufficient to keep the blood in active circulation during diastole, as well as systole. Thus we conclude: 1st of all, the speed of the blood is in inverse proportion to the calibre of the vessels measured in sectional areas. 2nd. At each systole the rapidity of the blood flow is increased in the large arteries close to the heart. 3d. The rapidity is constant in the small arteries, capillaries and small veins. 4th. The speed is increased in the veins toward the heart. 5th. In the large arteries the influences of the inspiration retard the speed while expiration increases it. 6th. In the large veins the influence of respiration and the suction force of the heart causes an increase of the velocity of the blood.

Time Occupied by the Entire Circulation.—The width of the blood path, as we have said, determines the rapidity, thus regulating the slow movement where the blood requires longer time to perform its functions in the tissues, and the more rapid movement where the blood simply passes along an intermediate path. In this way the red corpuscles are found to spend a large portion of time in the capillaries where these corpuscles are brought into active connection with the tissues.

It is important from the Physiological standpoint to distinguish between the blood rate and the time taken by a corpuscle in making the circuit of the blood path from the left ventricle to the left ventricle again. Duration is considered in respect to the single corpuscle. The time has been estimated approximately, during which, for example, certain substances pass from the jugular vein on the one side to the jugular vein on the other side. Hering injected, some drops of a two per cent solution of ferrocyanide of potassium, examining the blood on the other side every five seconds; testing it, on the other side, with perchloride of iron so that when the ferrocyanide appears on the other side there is a formation of Prussian blue. Various experiments of this and of a similar nature have led the Physiologists to conclude that the duration of the circulation is approximately, in the horse, for example, thirty-one and a half seconds, in the dog, sixteen and a half seconds and in man about twenty-five seconds. Vierordt, says, that the time of

the entire circulation corresponds with the time occupied by twenty-seven or thirty heart beats. If we take, for example, the amount of blood in the body of a person weighing 140 pounds as about 5,632 grams. This would represent 5,322 cubic centimeters. Each heart beat drives out 172 cubic centimeters from the heart into the aorta, giving almost exactly thirty heart beats as the period during which the entire blood goes around circulation. Taking the pulse at its normal seventy-two, this would give us twenty-five seconds as the period or duration of the entire circulation.

Change in the size of Organs:—Mosso has invented an instrument, the Plethysmograph, for the purpose of marking the changes in volume. It has been found by the use of this instrument that the size of an organ depends upon the blood supply in it. In the organ the volume is found to change with each heart beat, being enlarged by blood forced into it and diminished when the muscular capillaries are emptied into the veins. The tracings that have been made by this instrument correspond very much with the pulse tracings, and also with respiration indulations. The exercise of a limb lessens the volume on account of the increase of the blood flow out of the capillaries into the veins, although this is partly due to the increase of the lymph. Similarly, mental strain, brain work and sleep produce a lessening of the volume of organs. The blood is so distributed through the body that each organ receives the necessary supply according to its requirements. The activity of an organ determines the blood to it. For example, the activity of the mucous membrane of the stomach or the increase of the muscular exercise as of the limbs, determine the blood flow into these organs. There are, however, some organs whose continuous activity determines a constant supply of blood to these organs; for example, the heart, the nerve centers in the medulla and the respiratory muscles. These organs seldom if ever vary in the blood supply found in the case of normal activity. Changes in quantity are compensated for, and this compensation leads to the accurate distribution of the blood through the entire body. For example, in the case of hemorrhage or the artificial withdrawal of blood where the loss does not exceed three per cent of the body weight the loss is very quickly made up. This restoration takes place too quickly to suppose that it is due to the withdrawal of fluid from the lymph. It is probably due as most Physiologists recognize, to vaso-motor action increasing the peripheral resistance and thus sending the blood out of the capillaries into the general circulation. If the loss exceeds three per cent of the body weight, the loss of blood seems to diminish the force of vaso-motor influence, thus preventing the rapid restoration of equilibrium. If blood, on the other hand, be injected into the circulation, no results are noticeable, if the vaso-motor center is intact. But if the spinal cord be severed, there follows after the injection of blood a rise in the blood pressure. This indicates the capacity of the vessel to hold a larger quantity of blood than that normally present in the circulation, the extra blood being contained in the capillaries and the small veins. When the quantity of blood is increased there is a diminution of the peripheral resistance by the activity of the dilator nerves so that the blood pressure remains normal, thus the increase or the diminution of blood does not materially affect the circulation, unless it is dangerously large on either side, that is in diminution or increase.

SECTION XVII.—The Movements of the Lymph.

The spaces in connection with the connective tissue of the body constitute the origins of the lymphatic system. Certain constituent elements

of the blood plasma ooze through the vessel walls into those spaces. From these spaces there is a constant flow of the lymph through the lymph capillaries into the larger lymphatic vessels through the thoracic duct and the great lymphatic trunk into the blood circulation. The lymph, first of all, is presented in those inter-spaces between the tissues, those inter-spaces being in constant communication with one another, and also with the small lymphatics, which, as they pass to the larger lymphatics assume the form of lymphatic veins. Those lymphatic veins have delicate walls and are arranged with a large number of semilunar valves with dilatation in the lymphatic vessels above the valves. These valves always open away from the inter-spaces and thus render efficient assistance to the lymph flow in its forward movements from the inter-spaces toward the larger lymphatic vessels. The smaller lymphatics are joined together in the formation of larger lymphatics. These larger lymphatics being all united together with the two main lymphatic trunks, the thoracic duct and the right lymphatic duct. The right lymphatic duct is short, being the terminal of the lymphatics of only a small portion of the lymphatic system. All the other lymphatics terminate in the thoracic duct. The thoracic duct runs along the entire extent of the thoracic cavity. These two main ducts have very delicate walls, also, a valvular arrangement so as to promote the movement of the lymph away from the smaller lymphatics and to prevent lymphatic regurgitation. The two main ducts terminate on the two sides of the neck where, at least in the human subject, the duct cavity unites with the junction of the subclavian and the internal jugular veins, in the formation of the innominate vein. At this junction of the ducts with the veins there is a valvular arrangement permitting of the passage of the lymph into the veins but preventing the passage of the blood from the veins into the duct. Throughout the serous cavities of the body there are, also, found the beginnings and terminals of the lymphatic systems, these serous cavities being large surfaces in the lymphatic circulation. Here and there in the course of this lymphatic circulation there are found lymphatic ganglia constituting the lymphatic glands through which the smaller lymphatics pass.

These glands present, at least from the standpoint of the circulation, a resistance very similar to the peripheral resistence found in the capillaries in connection with the blood circulation. Thus, the analogy between the lymph in the lymphatic circulation and the blood in the blood circulation is almost complete. The lymph circulates from the lymph spaces, through the lymphatic vessels, and the lymphatic ducts, terminating in the venous junction in the neck, and thus is brought into close connection with the blood system. The tissues of the body are nourished by the fluid that is transuded through the capillary walls. Part of this fluid passes into the living tissue, and the balance is carried away in the form of waste. In all the tissues of the body that receive blood, the lymphatics are found very abundant, particularly in the region of the arteries and of the veins. The lymph does not pass directly into the blood, but through the lymphatic glands. The lymphatic vessels contain delicate walls from 2-10 to 6-10 mm in diameter. These delicate walls of the lymph vessels consist of three coats. 1st. of all, the intima of endothelium and elastic fibers. 2nd. The media of transverse muscular fibers and also elastic fibers. 3d. Adventitia consists of connective tissue, intercalated by elastic tissues and smooth muscular fibers. The minute lymphatic vessels consist entirely of endothelium cells. These endothelium cells being formed into capillary bundles, all of them opening toward the periphery. The fluid which has been exuded from the blood

vessels, passes into these minute lymphatic vessels by the process of osmosis or as some Physiologists think, through the lymphatic openings that are embedded in the tissues. According to some Physiologists, the theory of osmosis is not correct; they say that in the very minute lymphatic vessels there are delicate mouths, or openings which pass down into the lymphatic spaces, and each one of these openings represent a mouth through which the lymph passes out of the spaces into the minute capillaries.

Along the lymphatic path there are, as we have seen, lymphatic glands, small, rounded bodies of varying sizes, representing the collection of the lymphatic vessels at certain points along the lymph path. On the one side of these glands there is a small fissure in which the lymph vessels are found to arise. The gland is covered with a sheath of connective tissue, and the gland is divided into a number of sections, forming a dense plexus in which there are embedded the smaller lymphatics, and from which arise the larger lymphatics. These lymphatic glands are very freely supplied with blood vessels, either on the surface, or in the fissure.

Nerves, also find connection in the gland, in what way this connection is established it is not known. The capillary system brings the blood to the different tissues and as the capillary walls are delicate there is a free osmosis through these walls under the pressure of blood in the capillaries. Under this filtration process the water in the blood together with the saline substances in solution pass freely without carrying any of the albuminous substances along. It is thus laden with oxygen which is of value in the process of respiration and nutrition for the upbuilding of the tissues. After the tissues take up what is necessary for them the lymphatics collect the excess carrying it off in the lymphatic system. Where there is a large excess of this fluid transuded from the blood, too large to be appropriated by the tissues and to be taken up by the lymphatics we have a condition superinduced in the tissues of the body to which the name of œdema is applied. This same condition may be produced by the constriction or the obstruction of the lymphatic circulation, producing a swollen condition of the tissues—for example, in dropsical conditions. Thus, the lymph originates partly from the blood and partly from the tissues of the body. The lymph passing through the glands, washing out these glands and in this way often collecting in the lymph stream a large number of lymph corpuscles. The lymph, itself, is a clear, colorless or pale yellowish fluid, transparent or slightly opalescent coagulating very quickly under the influence of fibrin, this fibrin being the same as the fibrin that we find in connection with the blood. The lymph clotting being almost the same as blood clotting. The chemical composition of lymph varies very much, resembling the blood plasma except in one particular, its poverty of albumin. The specific gravity of the lymph is about 1017 varying to about 1025. When the lymph is microscopically examined it is found to contain a large number of lymph corpuscles and sometimes a few red corpuscles. These corpuscles are smaller than the white blood corpuscles, although some Physiologists have said they are identical. The lymph corpuscles are globular in shape, consisting of a large nucleus with a narrow granular margin varying in size from 5 to 15 micra. In the lymph there is found about 1-10 per cent of fibrin the ferment of the blood and the ferment of the lymph. As the lymph is transuded from various vessels and tissues of the body it varies very much in its character as it is found in the different parts of the body.

The solid matter is usually much less than that found in the blood, being not more than 5 or 6 per cent. of the solid matter. The venous blood is

found to be much richer in solid matter, than the arterial blood, because the fluid part has been partly transferred into the lymph. There is found in the lymph varying percentages of albumen, smaller quantities of extractives a small proportion of salts together with slight traces of fatty substances with a large percentage of CO_2 and only a small trace of oxygen. In a hundred parts of human lymph it is estimated there are 95 per cent. of water and 5 per cent. of solid matter. Of this 5 per cent. of solid matter, 4 1-10 per cent. of albumen; 5-10 per cent. of the salts, 3-10 of the extractives and 1-10 the fibrin, with a trace of fat. In the lymph spaces, capillaries and minute vesels there is a large percentage of water, whereas, in the larger lymphatics there is an increasing percentage of solid, the number of corpuscles increasing in the passage through the lymphatic glands. The pericardial and peritoneal fluids are also lymph, containing at times less and at times more solid matter than the normal lymph, otherwise presenting the normal characteristics in corpuscles and composition. The amount of lymph varies from time to time in different regions. Active exercise increases the flow of lymph, as also the hanging of the hand, the swollen appearance resulting from the increase in lymph and blood in the veins. Similarly the skin and tissues ma ybecome shrunken on account of the absence of the lymph. In 24 hours it is estimated that lymph is formed equal to 1-10 of the body weight. The lymph is so important in sufficient quantities that death very soon supervenes if the lymph loss becomes excessive, so that its existence in normal condition and its circulation are necessary for life. In man there are said to be no lymph hearts, such as have been found in connection with the frog, these lymph hearts in the frog giving rise to certain rhthmical contractions. According to some physiologists, there do exist lymph hearts in the human subject. Where these lymph hearts exist they consist of small dilatations with striated muscle fibres in the walls. Where they exist their pulsation is not in any way connected with the heart beat. In connection with the lymphatics unstriped muscle fibers are found in the walls and it is said that pulsations take place in connection with the muscle fibres as it is more probable that these fibres regulate the calibre of the lymphatics under the influence of the nervous system.

The lymph flows with a great rapidity through the thoracic duct into which the lymph is continuously being poured from the smaller lymph vessels and also from the lymph spaces. The forward movement of the lymph depends upon a number of circumstances. The lymph moves, as we have seen before, from the roots of the vessels toward their trunks. This movement is slow as compared with the movements of the blood; hence, it is estimated by the Physiologists that in the lymphatics of the neck, for example, the lymph flow represents 4mm. per second. We have four circumstances or conditions that influence the movement of the lymph, these we will specify: 1st of all, the valvular arrangement of the lymphatic system, as in the case of the veins, the lymphatic vessels are materially influenced by the pressure of the skeletal muscles. The valves of the lymphatic system prevent the lymph from flowing backward, always forcing the lymph forward toward the venous system and preventing the regurgitation of the lymph. In the case of a divided lymphatic vessel the simple motion of bending or straightening a limb, produces a profuse discharge of the lymph, this discharge being due to the pressure exerted by the muscles. In this way muscular movements tend to increase all the time the lymph movement, along the lymphatic path. The entrance from the thoracic duct into the venous system is protected also by a valve so that the lymph must flow

freely in one direction from the lymphatic system into the venous circulation and the blood cannot flow from the venous system into the lymphatic system. 2d. Lymph pressure. The pressure of the blood in the capillaries and in the smaller vessels is very much larger than in the larger arteries, producing, as we saw, the blood flow from the capillary system always toward the heart. In the lymph spaces the lymph also is subject to considerable pressure, along the lymph path, also, the lymph flow in effectively sustained by the valves, as we have seen, which keep it up in one direction. In addition to this, at the close of the lymphatic system in close proximity to the venous system the pressure always varies from a slight positive to a slight negative. In the lymph spaces where lymph originates, the pressure is estimated about one half of the blood pressure in the capillaries; that is from 12 to 27 mm. of mercury. Along the lymph path ther is, also, a resistance continuously met with, causing the lymph to accumulate in the lymph spaces of the tissues. This accumulation under the influence of resistance being balanced normally by the muscular activity of pressure of the muscles causing the steady onward flow of the lymph along the lymphatic path. On account of the difference in the pressure, between the blood and the lymph, in the capillary system, exudation takes place from the blood to the lymph spaces.

This pressure which causes the transudation of blood from the blood into the lymph spaces marks the highest point in the lymph pressure, determining, as we have said, the origin of the lymph current away from the lymph spaces that are found in the tissues toward a lower pressure, which is found at the junction of the lymphatic and the venous systems. This difference in pressure at the origin, and at the close of the lymphatic current always determines the lymph flow in the one direction toward the venous system. 3d. The Influence of Respiration. At every inspiration the pressure in the large veins near to the heart becomes negative, sucking, as we have seen, the venous blood, always toward the heart. Side by side, with this suction action that we find in the venous system, we find the suction force of inspiration, also pulling the lymph from the openings of the thoracic duct and the right lymphatic duct into the venous system. The thoracic duct lies inside the thoracic cavity so that at each inspiration the duct becomes somewhat expanded, setting up in this way, a certain suction action reaching backward to the lymphatic vessels that are outside the thoracic cavity, and always tending to pull the lymph, 1st of all, toward the great duct, and then from the great duct into the venous circulation. 4th. In addition to these three influences we have, also, two other influences upon which Physiologists, however, are not fully agreed. These two influences are, (1st.) The pressure arising from the osmosis. (2d.) The pressure arising from the muscular contractions of the lymphatic walls. The blood pressure in the capillaries throws out the fluid as we have seen, into the lymph spaces, thus originating, at least, the lymph flow from these lymph spaces. The increase of blood pressure increases at the same time and the decrease of the blood pressure decreases at the same time the current of the lymph, so that the flow of the lymph depends largely, if not altogether, on this origin in the pressure of the flow in the capillaries. The walls of the lymph vessels, as we said before, are muscular, especially at the valvular regions. These dilated regions are said to contract after the same fashion as the heart during systole. This adding to the force which drives the lymph always onward from the lymph spaces to the larger lymph vessels. These movements, however, in the human subject, are only ideals,

because so far, no experiments have been made to indicate that there are such lymph hearts.

These lymph hearts, as we said before, do exist in the frog, but whether they exist in the human subject or not is simply a matter of theory. From the standpoint of theory the pulsation of these lymph hearts seems to present a possible explanation of a certain amount of pressure brought to bear upon the lymph in its onward movement.

The combination of these influences tends to produce a steady lymph flow toward the larger duct, even against the force of gravity, this flow is steadily maintained from the lower limbs; especially by the valvular arrangement, preventing a backward flow. It is also supposed by some Physiologists that from the analogy of the blood circulation that the nervous system exercises an immediate influence on the distribution of the lymph and in its circulation through the lymphatic system. This, however, has not yet been demonstrated by physiological experiments. In the passage from the blood to the lymph there are two characteristic stages. (1st.) The passage from the blood to the lymph spaces and (2d) The passage from the lymph spaces to the lymph vessels. These lymph vessels are not always closely connected with the blood vessels. Hence, this has raised a difficulty in Physiology to explain the flow of the lymph out of the spaces into the lymph capillaries. Attempts have been made by some Physiologists to apply the principles of diffusion and of filtration to the passage of the lymph from the lymph spaces into the lymph vessels. The passage, however, through the vessel wall cannot be explained either by principle of diffusion or by the principle of filtration. The explanation becomes more difficult when we consider that a double passage takes place between the blood and the lymph spaces and between the lymph spaces and the blood, indicating that in addition to a purely physical principle of diffusion or filtration we must always take account of the Physiological condition of the vessel walls. According to some Physiologists the same process takes place in the passage of the lymph from the lymph spaces to the lymph capillaries as takes place in the passage of the fluid from the blood into the lymph spaces. This, however, is incorrect, because there are openings at certain points along the lymph capillaries into the lymph spaces forming a direct passage from the lymph spaces into the capillaries, whereas, there are no openings between the blood and the lymph spaces unless through the walls, as we saw before, when the fluid and sometimes the white corpuscles and sometimes the red corpuscles press their way through between the margins of the cells which line the walls of these blood vessels.

The quantity of lymph varies, the tissues demanding in certain circumstances more lymph, although it never normally exceeds a certain definite quantity. This limit may be exceeded in pathological conditions resulting in œdema. Oedema may be produced in one of two ways: an excessive transudation from the blood into the lymph spaces or by some obstruction to the transudation from the lymph spaces to the lymph capillaries. In the latter case an obstruction does not materially affect the lymph-flow as the anastomosis of the lymph vessels like the venous anastomosis opens up a free passage for the lymph in another path toward the ducts. Thus the real cause of œdematous condition is excessive transudation. These, however, belong to the field of pathology. The importance of the lymph circulation is evident from the close relation it bears to the blood circulation, from the amount of fluid that daily passes through the lymph circulation, and

from the dangerous effects resulting from the excessive accumulation of lymph.

The blood circulation depends upon certain factors, all of which vary more or less, the heart-beat, the peripheral resistance, the length of the vessels and their calibre, the elasticity of the walls and the valvular mechanism. These under the force of muscular contraction and relaxation and under the influence of the nervous system keep the blood in proportional distribution and normal circulation in the body. The quantity and quality of the blood, also exercise an influence on the circulation. It seems remarkable that the heart should go on continuously resisting temporary irregularities and overcoming temporary obstructions, and at last without almost any notice cease to beat and suspend life. Each heart-beat, however, involves an effort, and the effort is one to sustain life against the odds presented by all the resistances of the system. Thus the maintenance of life through the circulation of the blood with the analogous circulation of the lymph represents the most important factor in life. When we add to this the influence exerted by the nervous system upon the circulation keeping up the tonic condition of the vessels, and maintaining the distribution and circulation of the blood, we have the foundation factors of the life in the human system. Along the entire blood path, then move influences that during life are constantly playing a most important part in the upbuilding, general development and continued existence of the human life. If the statement of Dr. A. T. Still is correct, and we accept it with all the force of his life study behind it, "that a natural flow of blood is health; and that disease is the effect of a local or general disturbance of blood," then you can understand and appreciate the reasons that have led us to devote such a large portion of our time to the exhaustive study of the blood and the circulation, and at the same time feel that when we have completely mastered this subject, we have laid a solid physiological foundation for the rest of physiology and for the whole science of Osteopathy.

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CHAPTER IV. RESPIRATION.

SECTION I.—The General Statement in Regard to Respiration.

Respiration is essentially an interchange between the gases of the organism and the gases of the medium in which the organism lives. Oxygen is essential to the life of every tissue, whereas carbon-dioxide is destructive of organic life. The simplest organism, such as the amoeba and the infusoria when deprived of oxygen or placed in a medium that is over-charged with carbon-dioxide, become exposed to death, so that for the sustenance of these simplest forms of life, fresh oxygen must be brought into the system and the carbon-dioxide must be removed from time to time in order to the preservation of the organic life.

This interchange of gases takes place, constantly in all forms of animal life, from the lowest to the highest. In the lower organisms in which the structure is very simple and in which the life is very much less complicated, no complex mechanism is necessary, because these simple organisms are either directly plunged into the fluid upon which they live or have certain passages throughout their system in which the fluid passes to all the different parts of the organism. In the higher organisms in which the fluid circulates throughout the system, arrangements are necessary for an interchange between the gases that are found in the fluid and the gases of the surrounding substance of the bodily organs; for example, the tracheæ that are found

distributed throughout the bodies of insects, the gills that are found in the fishes. By this mechanism the air is brought into close relation with the fluid and thus introduced into the organic system, causes an interchange. In the higher forms of life we have differentiated organisms in the form of sacs with tubes communicating with the surrounding medium, the blood vessels lining the walls of this medium and furnishing the means of interchange between the internal and the external gases.

This sac, which is found very small in the lower animals, passes into the complicated honey-combed lung, the structure of which is of such a nature that cells, with minute capillaries, present a large surface in which this gaseous interchange is constantly taking place. In these highest forms of animal life there is a definite mechanism involving muscular movements and nervous action, for the purpose of introducing into, distributing in, and expelling the air of the gases from the organs of respiration. Thus the process of respiration becomes more complex as we rise in the scale of animal life. In amœbic life, the amœba lives in the fluid saturated with gases. In the higher forms of life, definite tracts exist for the admission and for the distribution of the gases, either directly, or as in the case of the fishes, by the admission of water containing in this case, the gases. In the still higher forms of life, as for example in the frog, there is a process of swallowing the air, by which the air is forced into the air sacs, while in the case of man we have a complex automatic action of muscles and of nerves, playing such a very important part in the process of respiration. The object of respiration is two-fold. 1st. of all, to take in a fresh supply of oxygen, such as is found necessary for the process of oxidation in the human body, and 2nd. to expell the carbon dioxide formed within the body. In the complex organisms, such as the human body, the phenomena of respiration may be divided into two parts. 1st. There is an interchange of gases which takes place between the blood and the tissues. This is sometimes spoken of as internal or inner respiration. 2d. In order that this process may go on successfully, there must also be an interchange between the gases in the blood and the gases of the surrounding atmosphere. In this way external air is introduced into the air cells of the respiratory organs. This interchange is called the external, or the outer respiratory process between the blood and the external atmosphere. In the human subject this process is carried on almost entirely in connection with the lungs, hence, this process of respiration is sometimes called pulmonary respiration. 3d. In addition to these there is a subsidiary respiration carried on in connection with the skin. This is called cutaneous respiration.

There is also a respiration carried on in connection with the intestines called intestinal respiration. There are also some changes that take place in connection with some other organs, but these are of minor importance. Both of these inter-changes are, in the main, physical processes rather than phsyiological, because they are due to the mutual diffusion of the gases and depend but slightly upon the epithelial cells that cover the surfaces through which the passage of these gases takes place. The respiratory apparatus, therefore, in the human subject, consists of the following mechanisms: 1st. The lungs with a large number of air vesicls and air cells connected together and in close connection with a dense plexus of blood vessels. 2nd The air passages leading to the lungs and communicating with the lungs. The air passages include the nose, the pharynx, the larnyx, the trachea and the bronchi, including the bronchioles. 3d. The thorax and the muscular mechanisms connected with it, by which the lungs are filled and emptied,

and 4th. The nervous mechanism of respiration. 5th, and last, the subsidery function discharged by the skin and by the intestines in the respiratory process.

SECTION II. *The Respiratory Apparatus.*

The larnyx is made up of several parts, forming a cartilaginous framework, the different parts of which are movable upon each other by means of certain muscles. There are three single cartilages: the thyroid, the cricoid and the epiglottis. There are three pairs of cartilages: the arytenoid and the cartilages of Santorini and of Wrisberg. The thyroid consists of two lateral plates which meet one another at an angle anteriorly forming the prominence known as Adam's apple and leaving between them posteriorly a wide open space. The cricoid cartilage placed between the thyroid, and trachea is shaped like a signet ring, the deep part being behind, the seal projecting upward. On the lateral part of the upper border of this seal there is on each side an open surface for articulation. The external surface of the cartilage is smooth in front but at the sides it becomes irregular and furnishes attachment to the crico-thyroid muscles and to the superior constrictors of the pharynx. The epiglottis is a plate of yellow elastic cartilage shaped like a leaf, the narrower lower part being attached to the deep surface of the thyroid cartilage in the middle line, the broad upper part projecting upward at the root of the tongue. In swallowing, this part is pushed downward and backward so as to be horizontally over the superior aperture of the larynx. During respiration its direction is vertically upward, the free surface curving forward toward the base of the tongue. It is covered with mucous membrane, a continuation of the lining of the pharynx and two folds of epiglotidean ligaments, underneath the mucous membrane being a number of small pits in which are lodged small glands opening on the mucous surface.

The mucous membrane of the larynx is thin and pale and has numerous glands opening on the surface, except at the upper and especially at the upper lateral part and over the true vocal cords, where it is squamous, the epithelium being ciliated and columnar. The mucous membrane is continuous below with that of the trachea; as it ascends it turns inward to pass over the edges of the true vocal chords. Again it passes outwards and then ascends a short distance on each side forming a fold, each fold overhanging the true vocal chord, and forming the false vocal chords. The true vocal chords are bands of elastic tissue covered with mucous membrane, this mucous membrane being very thin and adhering closely to the elastic bands. The false vocal chords are simply folds of mucous membrane. The superior aperture of the larynx is triangular in shape, wide in front where it is bounded by the epiglottis, and narrow behind where it is limited by the tops of the arytenoid cartilages and the cornicula laryngis. The sides of the superior aperture are formed by the aryteno-epiglottidean folds which slope downwards and backwards from the sides of the epiglottis. The superior aperture is closed during swallowing by the bending backwards over it of the epiglottis on the deep surface of which in the middle line is the cushion of the epiglottis by which the accurate closure of the epiglottis is secured. The larynx is abundantly supplied with blood vessels constituting a plexus in the sub-mucous coat, out of which arise a large number of delicate capillaries extending down beneath the epithelium. In addition there are two plexuses of lymphatic vessels, the one very delicate underneath the epithelium and the other less delicate underneath the blood capillaries. The nerves terminating in terminals pass through small glanglionic centers, forming connections with the nerve fibers entering the pharynx.

The Trachea.—The trachea or the wind-pipe as it is sometimes called is cartilaginous and membranous tube. It passes downward in the middle line from the cricoid cartilage about 4 ½ inches and then bifurcates to form the two bronchi, one for each lung, the division taking place about the level of the upper border of the 4th dorsal vertebra. The diameter of the trachea is from ¾ of an inch to 1 inch. In front and at the side the trachea is firm and resistant, this resistance being due to the presence of the transverse bands of cartilage. Those transverse bands of cartilage form imperfect rings ; the deficiency in those rings being behind where there is found a narrow compressible membranous portion of the trachea. Those imperfect rings are from 16 to 20 in number along the course of the trachea and sometimes they present a bifurcated appearance. Those rings are joined together by a coat which contains a medium proportion of elastic fibers. On the deep surfaces of this fibrous coating there are also found fibers of unstriped muscles, these fibers being arranged transversely. Within that fibrous coat is the sub-mucous coat in which are found a number of small mucous glands. The bronchi correspond in structure with the trachea. The right bronchus is wider, shorter and more nearly horizontal than the left bronchus. The bronchi entering into the lungs branch again and again forming finer and more delicate bronchioles, each of which ends in a dilatation; this dilatation being called the infundibulum. Changes take place ih the structure of the air tubes, as by this repeated process of branching they become narrower until they terminate in the infundibulum. The fibrous coating of these branches become thinner and thinner as the branch becomes smaller, and very distinct bundles of longitudinal yellow elastic fibers are found developing. The cartilage is found in small plates so arranged that together they completely surround the tube, making it quite cylindrical in shape. These plates of cartilage gradually become smaller and in the minute capillary bronchiole tubes they have entirely disappeared. The transverse muscular fibers form a layer all around about the inside of the tube inside of the cartilage, in the very finest tubes the muscle also, has entirely disappeared. The mucous membrane also gradually becomes thinner and more delicate as the tubes become smaller, but it still retains its columnar ciliated epithelium until just before the tube expands into the infundibulum, where we have patches of squamous epithelium.

Each of these finer bronchioles presents near to its termination, small recesses leading out from it, called the air cells. The tube ends in an inversely funnel-shaped expansion, known as the infundibulum. This infundibulum consists of a portion of the expanded tube, into which there open a number of air cells. These air cells have a wall of elastic tissue, lined by an epithelium of large, thin, flat cells, with smaller flat cells lying between those cells. Beneath this epithelium there is an extremely dense network of capillaries. The septa, between the adjacent air cells, are composed of a double layer of epithelium. Between these layers there is a single layer of capillaries, the blood in these capillaries being exposed to the action of the air on each side. The lungs are made up of bronchial tubes ending in the infundibulum, held together by connective tissue, which contains some pigmented corpuscles, and in which we find running blood vessels, nerves and lymphatics. The infundibula, or ultimate lobules, are there joined together into larger lobules, the outlines of which can be distinguished on the surface, and these lobules may be dissected from one another in the foetal lung. The lung surface proper, is divided by connective tissue into a large number of small lobules. The connective tissue

between the lobulees is continuous, with a thin layer of connective tissue, containing numbers of elastic fibers immediately below the pulmonary pleura. The inter-lobular connective tissue is highly developed in the case of children. The right lung is the larger, the broader, and the shorter of the two. The blood for the nourishment of the lung substance reaches the lung by the bronchial artery, and is returned by the bronchial vein. Branching out from this bronchial artery, we find minute vessels extending along the whole course of the bronchi, the bronchioles, the air vescicles and the infundibula, forming capillary plexuses, beneath the epithelium. The minute veins arise around the sides of the air cells, running along the sides of the air cells and then uniting together to form larger vessels pouring into the pulmonary veins. Each lung is completely invested with a serous membrane, the pleura, the viscral layer of this membrane being adherent to the surface of the lung, the parietal layer being reflected from what is called the root of the lung, where the bronchus and the blood vessels enter into the walls of the chest, the outer surface of the pericardium, and the upper hurface of the diaphragm. Beneath this coat there is a rich plexus of lymphatics which communicates with the deeper plexus in the connective tissue, binding together the small lobules.

From these lymphatics there arise vessels which run along with the bronchi and convey the lung lymph to the bronical glands. Nerve branches from the pneumogastric and the sympathetic are found scattered over the lungs, collected together in numerous ganglia, the minute branches being distributed to the muscle tissues of the minute blood vessels and to the walls of epithelium found on the surface.

SECTION III.—Mechanism of Respiration.

The movements in respiration consist of certain rhythmic changes, these rhythmic changes taking place in the thorax partly caused by contraction and relaxation of the murcles and partly dependent upon the elastic character of the organs. The thorax is a closed box containing two elastic bags which communicate with the external atmosphere by means of the common tube, the trachea. The lungs then form two large sacs divided up into portions or sections, each of which constitutes a small air vessel. These small vessels vary in size, the average diameter being about 1-100 part of an inch. Each air cell has ~~has~~ communication with the small bronchioles, these uniting in their common communication with the trachea. It is estimated that in normal human beings there are between seven and eight hundred million of these minute vessels, representing a superficial area open to the air in the lungs of 200 square meters. In addition to this vast surface, the wall of each air vessel represents a septum dividing the air from the blood in the capillaries, representing a vast vascular surface estimated at about 150 square meters. As the thorax is a vacuum, the pressure of the air inside the lungs stretches and expands these elastic structures so that they are always pressed against the thoracic walls. An increase in the volume of the thoracic cavity is followed by an expansion, and a decrease in the volume of the thoracic cavity is followed by a contraction of the lungs. The visceral and parietal layers of the pleura are thus kept in contact with one another. The fact that the lungs are always stretched is shown by what takes place when air is admitted into the cavity of the thorax (the pleura). Under such circumstances the atmospheric pressure exerts its influence upon the external surfaces (the pleural) and upon the internal surfaces of the lungs (the bronichal tubes and air cells.) This elastic bag then collapses, leaving the pleural sac full of air and indicating a condition which patho-

logically is known as pneumothorax. By the activity of the respiratory muscles, the chest capacity is extended on all sides.

This results in a greater atmospheric pressure than that upon the external surface of the lungs, and thus there is forced into the air passages of the lungs, a certain quantity of air which physiologically is called the new or tidal air until the pressure becomes equilibrated, the air remaining in the lungs normally being called the stationary air.

Inspiration is primarily a muscular action. In expiration the relaxation of the muscles, the lungs and the thoracic wall, on account of their elasticity assisted by muscular contraction, causes the chest to recoil into its former position. Thus the internal pressure of the lungs becomes greater than the external pressure and the air is forced out through the trachea. Expiration, therefore, is not purely a muscular action but a result of the elastic structure of the organs. Inspiration and expiration act together and these two stages constitute respiration. If the thoracic cavity is punctured after death, the lungs at once collapse, leaving a large vacuum between the lungs and the thoracic walls. This is due to the loss of elasticity which is found in the lungs when in normal life. During life the lungs are never completely exhausted of air, the air always lodging in the air cells. By inflation of the lungs they always tend to shrink so that they exert an influence upon the chest walls, depending upon the amount of distension, giving rise to the negative pressure which always exists in the thoracic cavity, that is, the pressure always below the atmospheric pressure which considerably influences as we have seen, the blood flow toward the heart. If the thoracic cavity is punctured upon one side only, then the one lung gives up its activity, resulting in the difficulty of breathing. If the other side is also punctured both lungs give up and hence we have asphyxia, because there is no lung expansion, the internal and the external pressure being equalized. The normal condition of the lungs, therefore, is that of partial distension.

In line with this idea, respiration never reaches its maximum of expansion. Complemental air may be forced into the lungs by means of a labored inspiration, due to the expansion of the thoracic cavity under strong muscular activity. Likewise, respiration never reaches its minimum of contraction, for the supplemental air can be forced out by muscular contraction.

Even in this latter case where considerable volume of air is expelled, there is always left what is called residual air. Partial dilation, therefore, is the normal condition of the lungs. There is constantly an elastic conflict between the pulmonary and parietal pleuræ, but this in normal conditions never results in the destruction of either of these because the air cannot penetrate the pleural cavity. In the case of the puncture of the chest wall the air penetrates the pleural cavity, the result being the separation of the pulmonary and the parietal pleuræ, thus forcing out the air through the trachea.

Even in such conditions there still remains a residual portion of air inside the lungs, the infundibula whose walls are soft retaining the air passed from the minute bronchioles. If, however, the air still freely comes into contact with the lungs, the air becomes absorbed, then the lung very soon loses the distended character and becomes hard. In the case of pleural puncture the air is driven out of the cavity, not through the lung at all but, of course, through the opening if the air does not enter the pleural chamber or if some obstruction blocks the puncture then the lungs may be normally distended until the puncture is healed without any g. at interference with respiration. In the fœtal life

there is no air in the lungs, the lungs being in a condition that we speak of as atelectasis, airless. The air cells in this condition have not yet expanded. Those air cell walls are lined with nucleated cells and well rounded cell substance, those cells being adhesive, no cavity having formed during fœtal life. The small bronchial walls also adhere to one another while the larger bronchial tubes and the trachea have a distinct tubular cavity, this cavity being filled, not with air, but with fluid, that is, in the fœtal life. The lungs in the child are in close proximity to the chest walls being separated only by the pleural membranes. At the birth of the child the first volume of air is admitted to the trachea and the larger bronchi passing with considerable force into the bronchioles and the air cells of the lungs, thus separating the walls and filling up the distended cavities. A large quantity of the first inspired air in the new born child remains within the air cells and the air passages and it is only later when they become fully distended that the expiratory process begins, the complete respiration being then established. Although the lungs are very elastic they cannot expell all the air out of the lungs because the air pressure on the internal surface is greater than the elasticity of the lungs and the elasticity of the chest walls. This pressure can be measured, and has been measured by a number of Physiologists. In the dead subject, for example, the manometer can be connected with the trachea. When the collapse takes place in the lungs, then the mercury in the manometer will be found to rise. Donders, a Physiologist, who has devoted considerable time to this subject, found the pressure under these circumstances to be from two to three mm. of mercury. During life this pressure is much greater and it is estimated that during life it is about 7½ mm. of mercury, 6 mm. at the close of a quiet expiration and 9 mm. at the close of a quiet inspiration; that is, this pressure represents about 1-100 part of the atmospheric pressure. In the case of complete forcible distension of the chest the pressure was found to be much greater, estimated to be about 1-25 of the pressure of the atmosphere or about 30 mm. of mercury.

Thus, the pressure upon the heart, and large arteries and veins, and the other organs inside the thoracic cavity would be 754 mm. at the close of a quiet expiration, and 751 mm. at the close of a quiet inspiration. In the living subject the expelling force is greater, because the muscular fibers of the bronchi aid the elasticity of the lungs. This, however, is small compared with the pressure of the lung elasticity itself. By introducing the manometer into the trachea of the animal, through a lateral opening there has been found normally a negative pressure during inspiration. This negative pressure being indicated by the fall of mercury in the manometer and, on the other hand, a positive pressure during expiration indicated by the rise of the mercury in the manometer. The same negative and positive pressure may be found by introducing the manometer into the trachea through the mouth, or the nostril, the amount of pressure being determined by the strength of the inspiration, and by the strength of the expiration. The negative pressure, therefore, increases according to the depth of the inspiration, that is, according to the extent of the lung expansion. During expiration it returns to the normal at the beginning of the stage of inspiration. The internal pressure of the chest cavity is called the intra-thoracic pressure, and it differs from the pressure inside the lungs, this pressure being called the respiratory pressure. The thoracic cavity may be enlarged on all sides. Ideally it forms a cone, the apex of the cone being placed at the neck, and the base of the cone resting upon the diaphragm, the sides of the cone being represented by the intercostal and the other muscles of

respiration together with the ribs, the sternum and the vertebrate column. On account of this an enlargement of the thoracic cavity lessens the pressure upon the lungs while a diminution of the thoracic cavity increases the pressure upon the lungs, these conditions favoring the inflow and outflow of air through the trachea, which is the only opening between the air and the lungs. This is the condition normally found in inspiration and in expiration. When the thoracic cavity enlarges the elasticity of the lungs yields, following as it were, the traction action of the chest, the two being in close apposition, and only separated from one another by the two pleural layers.

The spirometer has been made use of by some Physiologists, to measure the greatest amount of air that can be forced out of the lungs by the strongest, expiration, accompanying of course the deepest possible inspiration. The amount, as estimated by the Physiologists, varies from 2000 to 4000 cubic centimetres, of this amount about 500 cubic centimentres represent tidal air, or the new air taken in at each inspiration. From 750 to 1000 representing the supplemental air, 750 to 1000 representing complemental air and about 1400 cubic centrimetres, the residual air. All of these combined together constitute what is called the vital capacity of the lungs, that is, the sum of the tidal complemental, the supplemental and the residual.

INSPIRATION.—In inspiration the cavity of the thorax is enlared in two ways. 1st of all, it is enlarged vertically. The vertical diameter is increased by the contraction and the descent of the diaphragm, the anterior abdominal walls in this case protruding. In the human subject, the diaphragm is a partition wall separating the thorax from the abdomen, elliptical in shape, the convex part being direct toward the thorax. On the contraction of the muscular fibers, the middle part of the diaphragm descends and the diaphragm becomes flattened. From the sides the diaphragm descends further than from the central part. The cardiac portion of the diaphragm is said to descend from 5 to 11 mm. during normal inspiration. The arch is thus diminished in its height and on account of the attachment the first three lumbar vertebræ, to the lower six costal cartillages and the adjacent parts of the ribs there is always a tendency to pull in and also to pull up these lower ribs and also the costal cartlages, together with the lower end of the sternum. This is compensated for by the abdominal pressure. After the contraction of the diaphragm there is a negative pressure in the thoracic cavity, this pressure driving the diaphragm upward to the normal position in which the lower part of the diaphragm is in close proximity to the chest walls. This pressure downward is transmitted to the abdomen, especially to the anterior abdominal wall, producing a bulging outward and thus enlarging the thoracic cavity vertically during the process of inspiration. 2nd. The cavity of the thorax is also enlarged antero-posteriorly and transversely by the elevation and rotation on the antero-posterior axis of the ribs and by the carrying forward of the sternum. These movements are the result of muscular contractions. As the thorax enlarges the lungs also, necessarily enlarge, otherwise there would be left a vacuum between the pulmonary and the parietal layers of the pleuræ. This increased expansion of the lungs, means the rarefaction of the gases that are contained within the lungs, that is, the pressure of the gas inside the lungs falls below the pressure of the gas of the external atmosphere. The external atmosphere rushes down the trachea until the equilibrium is restored between the internal and the external. These two main causes of the enlargement, the descent of the diaphragm and the elevation of the ribs give us respectively the two kinds of breathing, said to be character-

istic diaphragmatic breathing, characteristic of the male and costal breathing characteristic of the female. Physiologists have found out that both of these characteristic forms of breathing are really present in every respiration, the one, however, prevailing over the other in the one case. These differences it is said by some Physiologists depend upon the difference in sexes. This, however, is untrue. The difference in breathing does not really depend upon difference in sex, but as has been said upon heredity, upon difference in the female costume as compared with the male costume. That this point is true is evident, for in the case of children of both sexes there is no difference in the form of breathing. The diaphragmatic characteristic male breathing being found in all children. The lowering of the diaphragm is mainly due to the muscular contraction. The elevation of the ribs and their rotation howeverare more complicated.

In the diaphragmatic breathing the vertical diameter is increased with a slight increase in the antero-posterior diameter. In the costal breathing, on the other hand, the antero-posterior and the transverse diameters are increased by the movements of the upper ribs raised by the scaleni muscles, producing what is characteristic of that form of breathing, the heaving of the chest, the diaphragmatic breathing, in this case, being reduced to a minimum. In the case of abdominal tumors, the breathing is thrown up into the clavicular region of the chest. In the adult life the antero posterior diameter is estimated at 165 mm. in the upper portion, and 190 mm. at the base; the transverse diameter at the axillae in the male is 260 mm. and in female 240 mm. In the case of the antero posterior and transverse enlargements of the chest the enlargements take place, as we said before, largely by the movement of the ribs. These ribs may be considered as radii moving on the vertebral arthrosis as a center. At rest the rib is obliquely directed from the spine toward the sternum. When it moves freely its sternal attachment moves forward more horizontally further away from the spinal center. As all the ribs have a slanting direction downward, on being raised they push the sternum forward; this forward movement being more or less according to the length of the ribs. The frontal surface of the chest is thus pushed forward and also upward according as the ribs are elevated. The rib arch, therefore, increases from the first to the seventh ribs, the elevation of the lower ribs thus increasing the antero posterior diameter and also the transvere diameter, thus making provision for a very considerable enlargement of the chest. This elevation of the ribs takes place by means of muscles. The muscles that are concerned in ordinary inspiration are the diaphragm, the external intercostals, some Physiologists also say the internal intercostals, the levatores costarum, the serrati postici muscles, both the inferior and the superior and also to some extent, the scaleni muscles. Aside from the diaphragm the external intercostals are the most important in connection with inspiration. The act of elevation over the entire chest is greatly assisted by the fact that the second rib is more movable than the first rib, thus furnishing a more solid base upon which the muscular action rests. Each rib in turn from the first onwards supporting the next rib the scaleni acting as an additional base of support for the first two ribs, forming a solid foundation for the action of the external intercostals. In this way there is formed a very solid base for the action of the external intercostal muscles.

In deep inspiration the sterno-mastoid raises and supports the first two ribs, by pulling up the sternum and fixing the clavicle so as to form a solid foundation for the musculsr action of the chest. The serratus-posticus

superior also raises the upper ribs, fixing the 2d rib, and raising the 3d, 4th, and 5th ribs, the serratus-posticus inferior aiding the diaphragm by drawing the lower four ribs backward, and in deep inspiration downward; the quadratus lumborum and the other muscles, by depressing and fixing the lower ribs form a solid basis for the contraction of the diaphragm, and thus, materially assist in deep inspiration. The intercostals, according to some Physiologists, aid in inspiration; according to others, the parts of the intercostals between the sternal cartilages act as inspiratory muscles, while those parts between the ribs act as expiratory muscles. According to other Physiologists the intercostals take no part in inspiration, simply acting as strengthening muscles, to render the intercostal spaces, and the whole of the chest cavity, firm and solid, giving tension, therefore, to the intercostal spaces.

In forced inspiration certain other muscles are brought into play, for example, the scaleni muscles, give a firm support to the first two ribs. The serratus-posticus superior gives fixity to the 3d, 4th, and 5th ribs, and by their contraction, the contraction of the scaleni and serrati being vigorous, they raise those ribs. The false ribs become lowered and then fixed, adding support to the diaphragm so that it vertically enlarges the chest. In artificial respiration and in forced respiration, with the fixation of the upper limbs, the pectoralis minor, the serratus magnus and the ilio-costalis aid in inspiration, elevating the ribs, and thus increasing the size very materially of the thoracic cavity. In fact all the muscles of the body which can either raise the ribs or aid in fixing the other muscles, are brought into play in forced inspiration.

EXPIRATION.—In normal expiration the walls of the chest and of the lungs, as we said before, recoil. In inspiration the lung tissue is stretched, this tension continuing as long as the muscle contraction lasts. As soon as the inspiratory muscles relax, the elasticity of the lungs comes into action and drives out a quantity of the air. This expulsion being due, not to muscular action but to the elastic recoil of the muscles. By the ascent of the diaphragm and the springing back of the ribs to their normal position, the cavity of the thorax is decreased. The lungs, therefore, during expiration occupy a much smaller space than before during inspiration. This means then, that their contained gases must occupy a smaller space than they did during inspiration.

Hence the pressure inside the lungs becomes greater than the pressure of the external atmosphere. The gas under this pressure rushes out of the lungs through the trachea in order that a state of equilibrium may be regained. Inspiration, as we said before, is the result of muscular action; whereas, expiration is a passive process, at least in the case of ordinary expiration, being in the main the result of elastic recoil, this elastic recoil being due to the lung tension and also to the tension of the costal cartilages, the intercostal spaces and the abdominal walls. The elastic lungs and the ribs as soon as the muscles of inspiration relax or let go their hold upon the chest spring back to their original form and size. Ordinary expiration is not, then, the result of muscular contraction. Some Physiologists hold that the intercostal muscles, especially the internal, act as expiratory muscles by depressing the ribs. After normal expiration the lungs are in a condition of elastic tension. When the muscles of inspiration cease to act, this tension comes into operation. The borders of the costal cartilages which are twisted upward and outward during inspiration, become during expiration untwisted. The intercostal spaces which were stretched during inspiration react and loose the distension during expiration. The diaphragm also re-

laxes pressing back the abdominal walls into their place and pushing up the diaphragm into its normal resting position. In addition to these influences there is another influence, the weight of the chest wall, this weight of the chest wall tending to return the chest to its normal position. It is generally supposed by Physiologists that the internal intercostal muscles contract during expiration, acting the part, therefore, of depressors of the ribs. This activity, however, is probably to maintain the tension of the intercostal tissues, not to depress the ribs. When this expiration becomes forced certain of the muscles become active. The internal intercostals, for example, during forced expiration are very active, at least when the lower portion of the thoracic cavity becomes fixed, this fixation taking place through the action of the abdominal muscles. The fixation is accomplished by the contraction of these abdominal muscles pressing the abdominal viscera against the diaphragm, causing the diaphragm to be pushed upwards, diminishing the vertical measurement of the thorax. The triangulares sterni lying behind the costal cartilages reach upward and then outward from the lowerend of the sternum, the deep surface of the ensiform cartilage and the cartilages of two or three of the lower sternal ribs to the lower and the deeper surfaces of the cartilages of the 2d, 3d, 4th, 5th and 6th ribbs. In this way we have the depression of the cartilages during expiration.

The serratus posticus inferior arising from the spines of the last two dorsal and the upper two lumbar vertebræ, passes outward, upward and forward, being inserted into the lower borders of the last four ribs. During expiration they pull the ribs downward and then backward. The levatores ani come together from the pelvic wall forming the greater part of the muscular floor of the pelvic cavity and acting as a resistant to the downward pressure of the viscera produced by the strong contraction of the abdominal muscles. The abdominal muscles assist in lessening the thoracic cavity by presenting a solid foundation upon which the internal inter-costal muscles act by pulling in the lower part of the sternum and the lower ribs, and by causing the diaphragm to move upwards by the force of the abdominal viscera. As expiration becomes more forced all the muscles which can aid in depressing the ribs or which can assist in giving fixation to the muscles, are brought into play so that the entire body according to its muscles and cartilages, is brought into action in forced expiration.

Associated with these movements of the thoracic walls, which take place in respiration, certain other muscular movements also take place. The currents of air that pass in and pass out of the lungs travel through the nasal cavity, more especially along the inferior nasal meatus. With each inspiration there is slight expansion of the nostrils, due to the contraction of the dilatores naris and in this way the entrance of air is assisted. By passing through the nasal membrane warmth is imparted to the air and the mouth is also protected from the dryness of the air. During expiration on the other hand, the nasal cartilages spring back to their original size, their normal form and position, aided by the compressores naris. The soft palate is moved backward and forward by the current of air ingoing and outgoing during inspiration. The glottis is wide open, while during expiration the arytenoid cartilages approach each other and the cartilages of Santorini project inward. Thus simultaneously with the movements of the alæ nasi and the thoracic walls there is a widening and a narrowing of the glottis. When this breathing becomes labored, the mouth is generally thrown open, the soft palate arises under the influence of the levatores palati, the larynx descending by the action of the sterno-hyoid and the sterno-thyroid muscles

and the glottis is thrown wide open as the result of the action of the posterior crico-arytenoid muscles, the naris being distended by the action of the posterior and the anterior dilatores nars and the alæ are raised by the levatores labii superiores alæque nasi the muscles supplied by the facial nerve being brought into action in opening the mouth.

The muscles of respiration are as follows:

First of all, the diaphragm. The diaphragm is the principal inspiratory muscle. On the contraction of the diaphragm the central part descends and it becomes less convex above, increasing the diameter of the thorax and the depth of the posterior part of the cavity. The phrenic nerves together with the sympathetic fibers furnish the nervous connection.

2. The levatores costarum arise from the points of the transverse processes of the highest dorsal vertebrae and the seventh cervical, passing downward and outward they find insertion in the external surface of the rib associated with the vertebrae. These muscles are rib elevators and are supplied by the intercostal nerves.

3. The intercostales externi. These pass between the ribs passing downward and forward, extending from the rib tubercles to the external cartilages. These muscles are also rib elevators and are provided with nerve connections in the intercostal nerves. The intercostales interni between the cartilages also assist in the elevation of the ribs.

4. The sterno-cleido-mastoids pass from the mastoid process to the sternum and the clavicle, assisting in the elevation of the upper portion of the chest in deep inspiration. These muscles are connected with the spinal accessory nerve and one of the branches of the second cervical.

5. The scaleni muscles assist in pulling up the first and second ribs under the fixation of the neck, being supplied with nerve connection by the cervical nerves.

6. The serrati postici superiores elevate the ribs in the upper part of the chest in forced inspiration, being supplied with nervous connection by the intercostal nerves.

7. The pectorales majores and minores, when the shoulders are fixed, assist in elevating the ribs, being supplied with nervous connection by the anterior thoracic nerves.

8. The trapezei muscles assist in fixing the shoulders, being furnished with nerves from the 3d and 4th cervical, and from the spinal accessory. The rhomboidei muscles also assist in the fixation of the shoulders, forming the base for the action of the pectorales muscles, receiving their nerve branches from the 5th cervical.

9. The erectores spinæ are complex muscles reaching along the sides of the spinal column, straightening the spine and assisting in the elevation of the sternum. They receive their nervous connection from the spinal nerves.

10. The intercostales interni run downward and backward from rib to rib, acting as depressors of the ribs in expiration. These muscles being chiefly used to preserve the intercostal pressure. The intercostal nerves supply these muscles.

11. The serrati-postici inferiores arising from the spine, running outward and upward, to be inserted into the lower edges of the last four ribs, drawing the ribs downward and forward, and increasing the lower part of the chest cavity. These muscles are supplied with nervous connection from the intercostal nerves.

12. The abdominales muscles press upon the abdomen, pushing upward

the thoracic base and aiding in the expulsion of air from the lungs. These muscles also assist in pulling down the ribs and contracting the diaphragm, thus aiding in expiration. They are supplied with nervous connection by the lower intercostal nerves.

13. The triangulares sterni draw downward the attached costal cartilages in expiration, these muscles being supplied with nervous connection by means of the intercostal nerves.

SECTION IV.—Respiratory Movements.

From what has been said it will be evident that each respiration consists of, 1st, the period of inspiration. 2d. The period of expiration, and 3d. The short period of pause during which there is no movement. In normal breathing the respiratory movements follow each other in regular succesion, the expiration being longer than the inspiration. In certain circumstances, as for example, in the case of the excitation of the vagi inspiration becomes two or three times longer than expiration. This, however, is an abnormal condition due to irritation. The pause may be either long or short, the length of it depending largely upon two things, 1st of all, habit, and 2d, will. In quiet breathing the pause occupies about one fourth of the whole period of respiration, the pause being shortened if respiration is very active and being increased during sleep, unconsciousness and mental abstraction. The respiratory rate also depends upon difference in age, position, species, temperature, that is, internal temperature, the seasons of the year the activity of the body and the digestive process.

In the normal adult the respirations number about 15 to 17 per minute, that is, about one respiration to four or five cardiac pulsations. These respiratory movements are more frequent in the child and are influenced largely by the movements of the body, exercise, etc. In old people the average rate of respiration may be found reduced to ten or eleven per minute. It is said by some Physiologists that the size of the body affects the rate of respiration, the smaller the body the more frequent being the respiration. In the male, and in children inspiration depends chiefly on the descent of the diaphragm and the breathing is abdominal. In the mature female the chest capacity is increased transversely and antero-posteriorly, the breathing being principally thoracic or costal.

When the inspirations are very deep, the distinction between the costal and the diaphragmatic breathing disappears altogether. During sleep, the difference of breathing in the sexes also disappears; the respiration during sleep being entirely ~~thoracic.~~ By the use of the stethoscope in connection with the larynx and the trachea, two sounds are heard, the one inspiratory and the other expiratory. These are called the laryngeal and the tracheal sounds which are harsh, articulate, the inspiration and the expiration being of equal length with a distinct interval between them. To the right or to the left of the manubrium of the sternum, similar sounds are heard. These sounds, however, are less intense and are called bronchial sounds. Over the posterior tube of either lung, heard either from the back or from the chest, we find respiratory murmurs, two low rustling sounds, the expiratory sound being ⅓ of the length of the inspiratory sound, with no interval between the two These sounds are produced by the air passing through the trachea the bronchial tubes and the lungs. In abnormal conditions the murmurs assume different forms, called rales or souffles. Listening to these sounds during speech produces certain special forms, which are called pectoriloquy when the voice sounds through the trachea, bronchophony when

sounded through the bronchial tubes, no audible vocal sound being heard in connection with the lungs. By fluid effusion into the pleural cavity a peculiar vocal sound is heard over the middle and posterior part of the thorax. This sound is of a short tremulous and a sharp character, also peculiarly metalic in its character, called ægophony.

The amount of air passing into and issuing from the lungs may be measured by means of instruments, these instruments being called the spirometers. The Hutchinson spirometer is the best of them. This instrument is made on the principle of the gasometer for the purpose of storing gas. Casella has invented an instrument on the principle of the anemometer used for recording the velocity of wind by Meteorologists. Bergeon and Hastus have also invented an instrument which they call anapnograph. A valvular plate forms one side of a rectangular box. It is connected by means of a tube with the mouth attached to the axis of this plate, there is a light lever with the point which writes upon the blackened paper surface moved by clockwork. The air passes through the tube into the box and comes into contact with this valvular plate, the pressure changes being transmitted to the valve and being recorded on blackened paper surface. By the graduation of this instrument to suit small squares of blackened paper tracings can be taken which represent not only the air pressure but also the amount of air that is inspired and expired and the velocity of the air current. The elastic lungs, even after a forced expiration, still contain a quantity of air, this quantity of air being generally estimated about 100 cubic inches. This volume of air is called the residual air. At the end of an ordinary expiration the emptying of the lungs is not nearly so complete, an additional 100 cubic inches still remaining in the lungs. This second 100 cubic inches is called the supplemental air, so that after a normal expiration 200 cubic inches of air remain in the lungs. The amount of air that is taken in at each ordinary inspiration measures about 30 cubic inches, this is called the tidal air. By a deep inspiration the lungs may be made to contain an additional volumè of air roughly represented by another 100 cubic inches, this last 100 cubic inches being called the complemental air. Hence the maximum capacity of the lungs may be estimated at 330 cubic inches, Of this volume of air—330 cubic inches—only 230 cubic inches can be expelled by the most forcible expiration, following a very deep inspiration. The term, vital capacity is applied to this maximum amount of air that can be contained within the lungs. As a rule the vital capacity is greater in the male than in the female, increasing up to 35 years of age and after that period of life diminishing. It, also, increases normally with the height and the internal capacity of the chest. Each centimeter added to the height of the body representing about 52 cubic centimeters in the male and 30 cubic centimeters in the female. In the normal male adult of about 5ft in height the vital capacity would be about 2,350 cubic centimeters and in a female of the same height, about 2,000 cubic centimeters.

Various instruments have been invented for the purpose of recording the inspiratory and the expiratory movements. Marey's stethograph is, perhaps, the one that is most commonly used. The movements of inspiration and expiration are, 1st of all, communicated by a system of levers to a tambour passed through a rubber tube to a second tambour, which has a lever to record the tracing on the kymograph. In the case of the costal movements, the stethograph is always used. In the case of diaphragmatic movements, a long instrument is passed through the walls of the abdomen, between the liver and the diaphragm, so that the one end which is flat or

spoon shaped, rests between the abdomen and the liver, the other end which is pointed, rests upon the recording lever, while the walls of the abdomen act as a fulcrum, to the lever. In this way the movements of the diaphragm may be followed and traced out just as we found the tracing in connection with the arterial pulse and the heart pulsations. It has been found by studying these tracings 1st, that expiration succeeds inspiration without any pause. 2nd, that expiration is longer than inspiration, except in abnormal conditions. 3d. The inspiratory movements are sudden and abrupt as compared with the expiratory movements. 4th. There is an expiratory pause at the close of the expiration, this expiratory pause being normally very brief. These represent the four main points that now are settled in Physiology by the use of these instruments. In certain diseased conditions there is an inspiratory pause following the inspiration. When the respirations become abnormally irregular, then the pause is increased, this applies to the inspiratory pause, and also the expiratory pause. Some Physiologists have tried to measure the force of the inspiratory muscles. These muscles require to overcome both the thoracic and the pulmonary elasticity. These resistances may be measured by a tube with what is called the "T" junction connected with the short limb of the manometer, placed in the two nostrils, and then making an inspiration. The mercury rises in the short limb representing the negative pressure, estimated as ranging from 1 to 3 mm. of mercury in the normal case, and from 30 to 60 mm. in the case of forced inspiration. In quiet expiration a positive pressure is noticed, varying from 2 to 3 mm in the normal, and from about 80 to 120 mm. in forced expiration. By making an average we find that the inspiratory muscles need to overcome a resistance, amounting to 10 mm. in the normal, and about 80 mm. in forced inspiration. During forced expiration there must be a force sufficiently strong to overcome a resistance equal to the positive respiratory pressure of the lung minus the lung elasticity, or about 70 to 75 mm. of mercury. The lung elasticity may be measured also in normal respiration by the use of the manometer, the estimates representing it being about 6 to 8 mm. of mercury in normal respiration, and about 30 mm. of mercury in deep inspiration.

The lung contractility has also been measured by various Physiologists, although the contractility of the lung is smaller because the contractility arises from the muscle fibers of the bronchi and therefore, generally plays a very unimportant part in either inspiration or expiration. According to the various methods that are used in registering the movements of inspiration and expiration, tracings may be obtained slightly varying from one another, all of them being more or less imperfect on account of the difficulty of inventing an ideal method. Inspiration commences suddenly, advances rapidly, becoming gradually more rapid, being followed immediately by expiration, which begins rapidly and then gradually becomes slower. In normal breathing hardly any pause exists, although there is a slight pause whenever the respiration becomes unrhythmical. Marey's pneumograph which is largely used in connection with these measurements consists of a hollow elastic cylinder, the internal cavity being connected with a tambour. The cylinder can be strapped around the chest and so adjusted as to indicate all the movements. On the expansion of the chest the cylinder ends are drawn out and the air in the cavity becomes rarefied, the lever which is attached to this cylinder being lowered, the lever being raised when the opposite process takes place. In the case of the stethometer which consists of a rectangular framework made of two solid parallel bars joined to a cross bar. The free ends of the bars are arranged, the one

with a tambour and the other with a button attachment. The tambour carries on the metal plate of its membrane, a small button. When the chest diameter is to be measured by this stethometer, the instrument is placed around about the chest, the button at the one end being placed on the spine and the tambour on the sternum, the changes in the diameter causing variations of the pressure in the tambour receiver, these changes or variations of pressure being transmitted to the tambour recorder and recorded by the recording lever, on the traveling surfaee. Inspiration and expiration vary, as we said before, with age and also with the sex of the individual, the inspiration being briefer in the case of the female and in children and old people. Variations in inspiration and expiration are also found in certain abnormal diseased conditions. If the pneumogastric is divided or in pathological conditions involving the stricture of the air passages the expiration becomes shorter than the inspiration. In the case of the dilatation of the air vessels the expiration is longer. In the new born child the ratio of inspiration and expiration is about 1 to 2 or 1 to 3. In the adult this ratio becomes about 5 to 6 normally. Inspiration is more abrupt and sudden than expiration, the tracings that we have mentioned indicating the rapid movements of inspiration as compared with the slower movements of expiration.

The normal pause varies abnormally in abnormal conditions, representing either an inspiratory pause or an expiratory pause. During sleep the normal rhythm of the periods, both of inspiration and expiration is broken, particularly in the case of children and aged people. In the latter case this pause becomes sometimes characteristically expiratory. This disturbance of the respiratory rhythm, is characteristic of what is called the Cheyne-Stokes breathing, in which we find respiratory movements in a series, each series being separated from the next preceding and next succeeding series by a marked pause, The first respirations of each series are superficial, then the respirations gradually become deeper until they reach a maximum, after that they gradually become more superficial until the close of the series. This series normally consists of from 20 to 30 respirations. This kind of breathing we find in connection with cerebral pathological conditions, for example, uraemia or the toxic condition of the blood arising from the accumulation of urea, and it indicates always the near approach of death. The same or similar disturbances of the periodicity of respiratory movements are found in the last stages of asphyxia and in cases of poisoning by chloral or cu rare, and in certain stages of fevers caused by the absorption of septic substances. There is a marked variation in respiratory periods in the case of age, in the newborn child the average being about 45 per minute, in a youth of 15, about 20; at 30 years, about 18; at 35 ,from 17 to 15; and in old age, from 11 to 10. The position of the body influences the periods also, the lying posture representing a slower respiratory rate, the sitting posture a more rapid rate, and the standing or walking attitude the most rapid rate. During the night the respiratory rate is much less rapid than during the day, and during or after meals it is much more rapid. Muscular activity also increases the rapidity of respiration. The changes of temperature outside the body have almost no effect, while temperature changes in the body affect very considerably the rate, as it rises in the case of fevers very much like the pulse rate, the pulse rate and the respiratory rate in abnormal as well as in normal conditions being in a regular and almost invariable ratio of 1:4 or 1:4½. Psychic influences also affect the respiratory rate, mental excitement or volitional purpose exerting a strong influence on its rapidity,

SECTION V.—The Influence of Respiration on the Circulation.

The movements of respiration are accompanied by very characteristic changes in the circulation. If the blood pressure is represented in a tracing and also the pulse tracing, these movements can be noticed if side by side we place a tracing of the inspiration and expiration. If the brain of a living mammal is exposed by removing the skull there is noticed a rhythmic pulsation of the cerebral mass quite different from the pulsation of the brain arteries. These pulsations of the cerebralmass are simultaneous with the respiratory movements, the cerebral mass rising during expiration and sinking or yielding during inspiration. If the arteries of the brain are ligatured these pulsations will cease altogether, or if the venous blood is allowed to escape from the venous sinuses they will also cease. These pulsations arise, therefore, from the expirations and the inspirations that restrain or assist the blood flow from the brain. During inspiration the pressure of the blood in the large veins may be negative, that is, it may fall below the atmosphere, and the puncture of one of these large blood vessels may result fatally on account of the inspiration of air into the vessels, passing through the vessel into the heart. A venous pulse may be observed in these large vessels of the neck, the pulsation always accompanying expiration and inspiration. The expansion and the contraction of the thorax have a strong influence upon the blood flow through the thoracic cavity, indirectly influencing the whole vascular system. The blood pressure rises shortly after the beginning of inspiration, usually after a period equal to about two or three heart pulsations, and it attains its maximum after a short period following expiration. Afterwards the blood pressure begins to fall, reaching its minimum after the commencement of the succeeding inspiration. The pulse rate during inspiration is more rapid than during expiration, and the curve represented in the tracing is different. Blood pressure changes, therefore, result from the respiratory movements, the effects upon the blood pressure varying according to the character of the respiration. The lungs and the heart, as we said before, are suspended in an air-tight cavity, the thorax and lungs being distended through inspiratory action, the walls of the air-cells in the lungs having an elastic force depending upon the amount of the lung distension. This elastic force which tends to lead to the lung collapse, exercises a suction force upon the other organs inside the thoracic cavity. This negative pressure becomes stronger as the lungs are more fully distended. This negative pressure inside the thoracic cavity is called intrathoracic negative pressure. This intrathoracic negative pressure in the case of sheep, rabbits and dogs is said to amount to from 3 to 5 mm. of mercury.

The pressure on the chest organs must have been atmospheric pressure, minus the negative pressure, and also, minus the elastic force of the lungs—that is, 760 mm., minus 3, minus 9, or about 748 mm. In normal expiration there is a force pressing upon the chest, equal to the atmospheric pressure together with the positive pressure of expiration, minus the intra-thoracic negative pressure, that is, 760 mm. plus 2 mm., minus 6 mm., amounting in all to 756 mm. During respiration, therefore, the pressure upon all the thoracic organs, except the lungs, is always less than that upon the vessels outside the chest, that is, the pressure upon the organs in the thoracic cavity other than the lungs, is always less than the atmosphere, the negative intrathoracic pressure being greater during inspiration. Thus, the aspiratory action of respiration attracts the blood from outside the thoracic cavity

into the large vessels that lie inside the thoracic cavity, both during inspiration and expiration, more largely however during inspiration. The thoracic organs being suspended in an air-tight cavity. when the lungs are distended during inspiration, and the intra-thoracic pressure is increased, the heart which is a hollow elastic muscle, is also affected by this pressure. The effects however, are very different, being more favorable to the venous blood flow, and retarding the arterial blood flow. The chief influence, however, is upon the flaccid and yielding veins that lie close to the heart. If the chest cavity is opened the inspiratory action ceases to expand the lungs, and there is no distension of the heart or the large blood vessels.

If, however, in the living subject the trachea is compressed, the inspiratory action becomes greatest upon the heart, the highest influence upon the circulation being noticeable in these circumstances, hence, it is said the maximum influences of the respiratory movement is always upon the heart or on the vessels close to the heart. This influence, as we have said, is felt more upon the large vessels than upon the heart itself, on account of the fact that the heart is a strong muscular substance, whereas, the vessels are soft and yielding. In the large vessels themselves this influence is felt more upon the veins than upon the arteries, on account of the softer walls of the veins and the thicker, more unyielding walls of the arteries. During inspiration the pressure upon the aortic surface is less, the aorta being distended and the blood flow through the aorta being lessened, producing a fall in the blood pressure. The thick aortic walls will give way less to the distension than the thinner vein walls, so that inspiration does not materially affect the aorta and this effect is always counterbalanced by the distension of the large veins, and by the rapid blood flow out of the veins into the heart. This flow of blood from the lungs throws more blood into the heart, which passes through the heart and is thrown into the aorta. Thus the greatest respiratory influence is felt, in the relaxed and relaxing walls of the large veins. The lungs, the heart and the large vessels being suspended in the expandible cavity of the thorax in which they rest, the lungs communicate with the atmosphere, and the heart and the vessels with the blood vessels outside the thoracic cavity.

These are all subject to the influence of distension and contraction in connection with the respiratory movements. In the case of the lungs themselves, the blood vessels communicate with the external vessels, inspiration diminishing the pressure on the delicate walls of the pulmonary vessels assisting the dictension of these vessels and promoting the blood flow from the lungs to the left auricle without almost any appreciable effect in the pulmonary arteries. The minute capillaries on the air cell walls are also subject to greater pressure than the pulmonary veins in inspiration, and thus the flow of blood is stimulated. The thoracic aspiration may draw in air, this air being carried to the right side of the heart and to the pulmonary capillaries. If the amount of air that is sucked in is large, it causes an obstruction in these minute capillaries, often resulting in death. During expiration the negative pressure is lessened, the intra-thoracic vessels returning from their dilated condition to a normal condition. The pulmonary blood vessels are thus left free to relax and are also interpressed by the air pressure of the lungs and by the expiratory influences, resulting in the contraction of the pulmonary vessels. More blood is thus brought into the chest and also into the heart during inspiration and the blood flow through the lungs is more free, more blood finding its way to the left side of the heart and hence into the general sytemic circulation. This increased blood supply causes

the general blood pressure to rise during inspiration while it is lessened during expiration. In deep inspiration the elastic action of the lungs and the intra thoracic pressure become greatly increased; consequently the pressure upon the organs inside the chest is much lower than the pressure of the atmosphere. Forced expiration, on the other hand, produces a positive pressure, often amounting to 100 mm which added to the atmospheric pressure would represent about 860 mm; the intra thoracic pressure being lessened we must substract it, leaving 854 as representing the pressure on the organs of the chest. In this case the veins are very much enlarged and the blood is prevented from flowing into the heart, the veins presenting a characteristic venous pulsation during forced inspiration and forced expiration.

The blood flow to the right side of the heart is also assisted by the action of the diaphragm and of the abdominal walls, transmitted to the abdominal vesself. Arterial pressure tends to force the blood downward in the body and to restrain the blood flow from the heart, while the flow toward the heart in the venous system is increased on account of this respiratory movement. The arterial walls are so thick and so rigid that this influence does not materially affect the arterial blood flow, whereas, the venous walls being so thin and yielding, it tends to facilitate the flow of the blood toward the heart. The result of this would be seen in the case of the section of the phrenic nerves, producing diphragmatic paralysis, the blood pressure curves in this case being very much lessened. This is due to the diminished respiratory actions which are confined to the ribs and to the sternum. and also to the loss of the pressure communicated from the diaphragm to the veins.

The general effect, therefore, of inspiration, is to increase the blood pressure and the general effect of expiration is to decrease the blood pressure. The negative pressure in the thoracic cavity found during inspiration gives place to a gradual lessening of the negative pressure and to a diminution of aspira tion resulting from an intra-thoracic pressure below the atmosphere. The flow of the blood is also lessened because a smaller volume of blood passes through the large veins. The veins in the abdomen are now being refilled with blood and as the lungs contract, the vessels inside the lungs also contract, retarding the blood flow from the right side of the heart through the pulmonary circulation to the left side of the heart.

Hering has devised an instrument to illustrate the influence of the respiratory movements on the circulation. There is a large conical chamber representing the thorax, at the bottom of which there is a rubber representthe diaphragm. At the top of the vessel there is a tube entering into the chamber representing the trachea connected to the manometer from one side. At each side is a vessel, one filled with water representing the venous blood and the other empty, these two communicating by a tube with a long soft bag between the tubing, which represents the heart, the heart valves being at each end of the bag representing the valves in the heart at the orifices. In the cavity there are suspended from the tube representing the trachea, two sacks representing the lungs. If the diaphragm is pulled down from the center the air in the chamber becomes rarefied, the air passing through the trachea tube into the lung sacs; at the same time water is forced from the vessel on the one side with the heart sac which becomes dilated. The diaphragm when released is pulled up partly by the negative pressure in the cavity and partly by the diaphragm elasticity. Then the rubber sacs are emptied by their own elastic reaction. The heart sac contracts, forcing the fluid into the vessel on the other side, the flow being measured on the manometer. During inspiration there is a negative pressure in the thoracic

cavity gradually increasing during the inspiratory period, air being breathed into the lungs and blood being sucked into the large veins next the heart. During expiration this negative pressure gradually diminishes, the air being driven from the lungs and the blood being driven out of the distended veins into the heart. This blood flow into the chest during inspiration is assisted by the distension of the capillaries of the lungs and by the difference in pressure between the veins and arteries so that the blood circulation in the lungs is increased and the blood circulates with greater rapidity.

The aspiration of the thorax also assists in drawing the blood away from the liver, for when inspiration reduces the pressure on the inferior vena cava, the blood flow through the hepatic veins and the rather slow normal circulation in the liver becomes gradually accelerated. Some Physiologists believe that the rhythmical stimulation of the vaso-constrictor center in the medulla is influenced by respiratory actions. These rhythmical stimulations are said to take place simultaneously with the inspiratory action of the respiratory center. In the case of the human subject it is noticed that during inspiration the heart-beat increases, inspiration assisting, at least, in this way in increasing the general blood pressure. During expiration the pulse is less rapid than during inspiration. If the pneumogastric nerves be cut the pulse rate increases, but there ceases to be any difference in it during inspiration and expiration. If, however, the thorax be opened and the pneumogastrics left uncut there is still an increase in the rate during inspiration. Thus, the cardio-inhibitory center either increases in activity during expiration or else loses activity during inspiration, the cardio-inhibitory center and the respiratory center being associated in some way in their action. This sympathy between these two centers is supposed to depend upon the arterialization of the blood, the greater arterialization of inspiration affecting the cardiac centers, lessening its activity during inspiration and producing an increased pulse rate. Deficient arterialization of the blood affects the vaso-motor system. By placing an animal under the influence of curare so as to remove the complications arising from the skeletal muscle contractions, if both vagi are divided so as to check the inhibitory impulses from the center, artificial respiration becomes suspended. Following this there is noticable a rise in the pressure due to the stimulation of the vaso-motor center by the venous blood flow producing constriction of the small arteries, especially those of the splanchnic region. When the artificial respiration ceases the blood pressure rises, at first, steadily and then more irregularly. As the blood becomes more venous the vaso-motor centers and the heart become weakened. The blood pressure waves produced during normal breathing become more marked as the respiratory movements increase in depth. When the most powerful inspiration is made the lungs are fully expanded and the heart is also greatly distended, the intra-pulmonary and the intra cardiac vessels being also dilated. Although this induces a large flow of blood into the chest cavity, the heart beats may be small, because the negative pressure is so great that the thin walls of the auricles have to contend against a great pressure in contracting. Only a small quantity of blood is thus forced into the general circulation and the left auricle of the heart through the lungs. If there is a very strong expiration, followed by a very powerful inspiration, the mouth and nostrils being closed, the heart and the vessels become greatly distended, the blood current to the auricles and ventricles increases; the heart and lung vessels become gorged, only a very small quantity of blood passes into the systemic circulation, and the heart sounds and pulse may disappear. If then a pow-

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erful inspiration is made and then a strong expiration, the glottis being closed, there is high pressure in the lungs, the heart and large vessels, resulting in the drawing of the blood out of the pulmonary circulation into the heart circulation and through the arteries into the general circulation resulting in a rise of blood pressure, the veins outside the thorax being distended as seen in the veins of the neck and face, the heart being pressed on to such an extent that the heart sounds and the pulse may disappear.

In inspiration, and expiration into the spirometer the blood pressure curves are found to be altered. If the rarefied air is inspired, the blood pressure rises above the normal, and if an expiration takes place under similar circumstances, the blood pressure will fall, although it will continue above normal expiration. The rise in blood pressure arises from the effort required to inspire the air into the lungs, this effort being increased in connection with the other organs in the thoracic cavity, causing the blood to flow more rapidly through the pulmonary circulation. The air expired from the lungs into the spirometer tends to distend the vessels in the thoracic cavity and to assist the blood flow in the pulmonary circulation, when the vessels become gorged, and the extra-thoracic vessels become depleted, the blood pressure falls. If compressed air be inspired the inspiratory rise is diminished. If the air pressure is higher than the pressure of the elastic lung tension, the chest will distend without any muscle effort, resulting in a decrease inside of an increase of negative pressure, giving place to positive pressure. The heart and the other vessels in this case are compressed and the blood is forced out into the systemic circulation.

If expiration takes place into compressed air there is a temporary increase of blood pressure followed by a decrease due to the hindrance offered to the flow of blood through the heart to the lungs. These effects are noticeable in ballooning in which case there is added a complexity due to the pressure abnormally exerted upon the peripheral circulation. In the case of artificial respiration where bellows are used to force the air into the lungs, expiration taking place by the elastic recoil, after the lungs have been filled the capillaries are subject to the action of the positive pressure of the air in the lungs and the resisting force of the chest walls, the blood being drawn out of the lungs temporarily increasing the blood pressure to be followed by the decrease in pressure when the flow of the blood is retarded. When expiration takes place the pressure is taken away and the blood flow is promoted, a fall in the blood pressure existing until the vessels are filled, when there is a rise. If the air is expired out of the lungs the blood pressure rises on account of the distended condition of the lung vessels. Hence, in artificial respiration we find during inspiration that there is a temporary rise followed by a fall and during expiration there is a temporary fall followed by a rise in blood pressure. The respiratory system also bears a relation to other systems of the body. Deficiency in the oxygenation of the blood arouses the muscles in the alimentary canal to activity having also a material influence upon perspiration and possibly upon the other secretions. Respiration chiefly in connection with the respiratory center is also influenced by changes effected in the blood by the action of the skeletal muscles. Thus, the respiratory system is closely connected with all the bodily organs and may be said to act and react upon the system in general. Effort or work performed by the body results in depriving the blood of its oxygen and filling it with carbon dioxide. This change in the blood would affect the respiratory center and increase the activity of respiration to such an extent as to mark out the limits of deoxygenation and carbonization. This

creates activity of the respiratory system which in its relation with the other systems makes provision for that metabolism which provides for the repair of this wasting condition.

Respiratory action is aided by cardiac activity, and hence, the two go hand in hand in preventing that collapse which is sometimes represented as want of breath and at other times as heart failure. Hence muscular activity depends not upon respiration only nor upon the blood circulation only, but upon the concerted action of both of these. The proper distribution of air implies the proper circulation of the blood. It may seem that respiration is more important for muscular activity but circulation is as important. This abnormally is represented in the common expression, breathless applied to an exhausted person, the real cause and condition being more probably want of heart action. The great difference between the endurance of persons is found to be due not so much to want of air represented by a panting, breathless condition, as to the incapacity of the heart to keep up with the quickened rate of respiration. As we said before there is a normal ratio between respiration and heart pulsation. Wherever this ratio is broken down, energy is impaired by reason of the impairment of some one of the two actions, lung action or heart action, most commonly the heart action.

There are therefore, two main elements in respiration. 1st, respiration proper and 2d, the circulation of the blood, the former bringing the air to the blood and the latter the blood to the air. Of course, there is implied in this, the normal condition of the blood, its richness in haemoglobin, that is, in red corpuscles, for upon this depends the volume of oxygen that is taken from the lungs into the blood. That this is so is evident from the fact that anæmic persons are very easily made breathless because of the lack of blood supply, and hence the lack of oxygenation through the blood. The force of the mechanism of respiration can only deliver to the blood and to the tissues the oxygen, the blood itself must take in and utilize it in order that it may be of value to the system.

Certain changes taking place in the circulatory system affect the respiratory system. The supply of blood furnished to the respiratory center may and often does materially affect respiration. If the blood flow is suddenly taken away from the medulla we find respiration attended with difficulty and sometimes accompanied by spasms. The supply of blood to the medulla through the basilar artery and its branches, if interfered with in any way either by increase or diminution of the blood flow may effect the respiration, similarly the supply of blood to the lungs if abnormal interferes with respiration. The arterialization of the blood is accomplished by the blood flow through the lung capillaries by being brought into close conjunction with the air in the air vesicles. If the pulmonary arteries become obstructed or if the valves of the heart fail to act properly or if the cardiac beat be weakened the circulation of the blood from the pulmonary vessels to the heart is interfered with and hence, the amount of oxygen carried by the blood to the different tissues of the body is lessened on account of the decreased blood flow. In this way the blood circulating is less than normal and it is less arterial than normal, the nerves and muscular tissues being thus deprived of a chief part of their nutriment, the oxygen. This deficiency of oxygen manifests itself in connection with the medulla by dyspnœic conditions, the difficulty of respiration associates with this condition, sometimes leading to the more normal pulmonary circulation. The blood circulation and consequently the tissue nutriment thus depends to a large extent upon the normal respiratory action.

MODIFICATIONS OF THE THE NORMAL RESPIRATORY MOVEMENTS. The chief function of the thoracic expansion and contraction is to secure adequate lung ventilation. There are subsidiary functions however, discharged by these respiratory movements spoken of in Physiology as special respiratory actions. Some of these respiratory actions are volitional and some of them are spasmodic. Respiration in man is used as a means to give vent to the feelings and emotions. The volume of air expired from the chest is also used to expel certain substances from the upper air passages in this way providing for a clearing of these air passages so as to aid the normal respiration. Hence, we find certain peculiar acts which are not peculiarly respiratory, although they assist in the general economy of nature. These actions are all reflex, the movements being determined by some form of stimulation. 1st, COUGHING. Coughing consists of a deep inspiration followed by the partial closure of the glottis, and a sudden expiration during which the glottis opens forcibly and a volume of air is forced through the upper respiratories, in some cases foreign substances being expelled also. Coughing represents not only an abnormal state of the respiratories, it may also indicate an irritation of distant parts of the system, such as the stomach, liver, spleen, uterus. These are sometimes called sympathetic coughs. Coughing is either a reflex or a voluntary action. The afferent impulses are usually carried by the superior laryngeal, as for example, in the case of an irritant substance found in the larynx. Stimulation may also arise in connection with the vagus branches to the bronchial tubes and to the stomach. Stimulation, also, of the sensory nerves of the skin may produce coughing, as in the case of cold drafts of air. SNEEZING represents a deep inspiration followed by a strong expiration. This expiration being strongest in its passage through the nasal cavity, the opening from the pharynx into the mouth, being closed by the contraction of the pillars of the fauces and the falling of the soft palate. Sneezing is generally a reflex action, resulting from the irritation or the stimulation of the nasal branches of the fifth pair of cranial nerves. In the case of sneezing produced by a brilliant light the optic nerve is the afferent nerve. When the act itself is coming on, manifested as it may be by premonitary signs, it may be stopped by the firm pressure of the finger against the upper lip, or by the close pressure of the lower lip against the upper lip. In LAUGHING there is an inspiration succeeded by a number of spasmodic and interrupted expirations, the glottis being opened and the vocal chords vibrating freely at each expiratory movement. The expirations in the case of laughter are less forceful than they are in the case of coughing. The mouth is opened and the muscles of expression give to the face the facial characteristic expression.

In the case of CRYING the movements of respiration are somewhat similarly modified as in the case of laughing, modified, however, by certain muscular movements. It is this that makes it so easy to pass from laughing to crying and from crying to laughing. There are differences however in the rhythmical movements and also in the facial expressions. Accompanying crying there is, of course, a secreting process which produces the tears and also in laughing if laughing is carried to a large excess. In SOBBING which sometimes follows crying there is a series of convulsive inspirations, the glottis being partially closes so that little, if any, air passes into the chest In sighing, on the other hand, there is a deep and long inspiration largely through the nasal cavity followed by an expiration of shorter duration. YAWNING is also a deep inspiration during which the mouth is opened, usually accompanied by muscular contraction of the shoulders and of the back

and by the lowering of the under jaw. These movements are normally followed by short expirations. In SNORING the mouth is opened and air freely entering, passing in and passing out causing the palate and the uvula to vibrate freely. During inspiration the sound Is very marked and it may be absent during expiration. In GARGLING the throat the liquid used is sustained between the palate and the tongue the air being forced through the fluid producing the characteristic bubbling sound.

SECTION VI.—Changes in the Air During Respiration.

It is only in comparatively recent times that the necessity of fresh air has been recognized as one of the necessities of life. Older writers did not recognize the importance of respiration at all. It was supposed that by the inbreathing of air the air passed into the heart itself to cool the heated condition of the blood and to arouse the spirits. The idea of cooling the blood by respiration was the prevailing idea until the 17th century. It was in the 17th century that Malpighi discovered the existence of the air cells in the ungs. It was at this time that the air was found to be necessary to life and that exchanges take place between the air and the blood. Following this we find experiments that indicated the variation in the air breathed as a cause of life, muscular activity and healthy or abnormal life conditions. Following these was the discovery of carbonic acid and oxygen, the one given off from the body and injurious to life, the other taken into the body and beneficial to life. At this point the atmosphere was analyzed and found to contain two constituent gases varying in breathing and produces varying results when breathed. At the beginning of this century expired air was found to have lost oxygen, to have gained carbon dioxide and aequeous vapor, and to have become hotter. Many researches have been made with the subject of discovering the amounts of these substances. The method used has been to draw through a chamber in which an animal is placed a continuous current of air whose amount and composition are known.

If a certain quantity of air deprived of CO_2 consisting only of O and N passes through such a chamber some O is consumed and some CO_2. and aqueous vapor are given off. If the air is pulled in through tubes containing substances that will absorb CO_2 and the vapor is then the amount of CO_2 and vapor will be represented by the increase in the weight of the contents of the tubes. By such experiments as these various physiologists have found that about 500 C. C. at 30 cubic inches of air are taken into the lungs at each inspiration. If we calculate 15 to 17 respirations per minute this will represent about 1,080,000 C. C. in 24 hours of air inspired. While the air is in the bronchial tubes the tidal air makes certain inter-changes with the air inside these vessels. In an ordinary inspiration 30 cubic inches or 500 C. C. of air rushes into the upper part of the pulmonary passages pushing, as it were, before it the air already in the lungs which is called the stationary amounting to about 200 or 300 cubic inches. Diffusion now takes place between the new or tidal air and the stationary air, oxygen diffusing from the former downward into the letter while carbon dioxide diffuses from the latter to the former upward. At the next expiration following the inspiration 30 cubic inches or 500 C. C. of air is expelled, 170 C. C. of this is estimated as part of the air taken at the immediately preceeding inspiration, the remaining 330 C. C. being vitated air returned from the lungs. Hence, of the 500 C. C. taken into the respiratory tract by an inspiration, 330 C. C. remain in the pulmonary system gradually passing by diffusion down to the air cells and reaching these in the time occupied by about five

inspirations. In the expired air the first portions expelled are atmospheric air while the portions of CO_2 and aqueous vapor gradually increase in the air that is expelled in the later stages of expiration. The temperature of expired air varies but it is usually slightly above that of the inspired air. When the atmosphere is about 20°C the temperature of expired air in the mouth is about 34°C and in the nose 35.5°C if the temperature of the air sinks low, expired air falls slightly, for example, at 7°C the expired air is about 29°C. If the air temperature is high the expired becomes cooler than the inspired air, for example, at 40°C the expired air is 37°C. The expired air usually follows the blood temperature depending on the relation of the blood temperature to the atmosphere and the breathing rate, the change taking place not in the lungs but in the upper respiratories.

The average composition of atmosphere is about as follows :

In 100 volumes we have oxygen 20.90, nitrogen 78.80, CO_2 .05, but, of course, there is a percentage of vapor H_2O about .85. There are also slight quantities of nitric acid, carburretted hydrogen, ammonia, and also organic and inorganic minute substances. The aqueous vapor depends on the temperature, being higher with a higher temperature. The moisture, like the heat, is imparted not in the lungs but in the upper respiratories. Respiration, therefore, is influenced by the air temperature and also by the air pressure. When the temperature is high an air containing less oxygen is breathed. In order to counterbalance this loss of oxygen the respirations become deeper and also more numerous. The difference between the inspired and the expired air is an important element in connection with respiration.

(1). Inspired air has O 20.81 per cent; in the expired air that amount of oxygen is decreased to about 16.03. (2). The nitrogen is about 79.00 per cent in the inspired air, increased to about 79.50 per cent in the expired air. (3). The CO_2 varies in the inspired air from .04 to .05. In the expired air it increases to 4.38 sometimes to 5. (4). H_2O varies in the inspired air also in the expired air with the temperature. In the expired air the H_2O not only varies with the temperature but also according to the saturation of the vapor with certain substances containing a quantity of organic matters which give the odor to the breath and some of which are poisonous. (5). In the inspired air we find NH_3, the organic proportion varying with situation, etc. An atmosphere containing one per cent of CO_2 is far less hurtful in respiration than one containing the same portion of CO_2 added as a result of respiration of the living organisms in the atmosphere. In one breath, for example, the air has more CO_2 and less oxygen at the close than at the beginning of the breath. Hence, if the breath is held for a long time, that is, if we have a pause between inspiration and expiration the amount of CO_2 is greater in the expired air. In the case of expired as compared with inspired air we notice four or five different points. First of all, the expired air contains almost ~~almost~~ five per cent less of oxygen. 2d. It contains 100 times more of the CO_2. 3d. It contains about ½ per cent more of nitrogen. 4th. The expired air is generally hotter than the inspired air. The temperature of expired air is normally about 37°C. 5th. The expired air sometimes contains ammonia, carburretted hydrogen, and also the volatile gases. The volume of air expired at any one respiration is the same normally as the volume that is inspired.

The volume of expired air however, may be slightly greater than the volume of inspired air, but this is due to the expansion of the expired air resulting from an increased temperature. If both volumes, the volume of

inspired and expired air are measured at the same temperature, and at the same pressure, the volume of the expired air is slightly less than the volume of the inspired air, the diminution in volume amounting to 1-40 or 1-50 of the whole volume. This diminution is due to the fact that all the oxygen taken in during inspiration does not appear in the expired air as $C\ O_2$. Some of it having been retained and entering into the formation of other combinations within the body. It is estimated by the Physiologists that from 800 to 2,000 grams of $H_2\ O$ are given off by the expiration process in 24 hours. It is believed by Physiologists that the larger proportion of this comes from the moist walls of the upper respiratories. This conclusion is reached from the fact that dry air when it is inspired, becomes quickly moistened in passing through these respiratory passages. This gives us these results: 1st, that the air expired is saturated with vapor, the amount of water which a volume of gas can take up as aqueous vapor, depending on the temperature. The higher the temperature the larger the amount of aqueous vapor being taken up. The expired air is then saturated with this aqueous vapor and this saturation takes place, not in the lungs, but in the upper respiratories. 2nd. The volume of expired air is smaller than the volume of inspired air to the extent of about 1-40 or 1-50 of the volume of inspired air. It is estimated that 700 grams of oxygen are absorbed, and 900 grams of CO_2 in weight are eliminated in twenty-four hours. This amount of CO_2 represents 244 grams of carbon, and 656 grams of oxygen, so if we subtract this from the 700 grams absorbed, we have left 44 grams of oxygen disappearing through the body. We must consider, accordingly this fact that CO_2 is not only eliminated from the body by the lungs, but also to a slight extent through the skin, the estimate being that about 1-140 of the entire volume of CO_2 eliminated from the body is eliminated through the skin. These numbers, of course, are subject to wide variation, depending upon the conditions of the individual, also upon the condition of the air that is breathed.

Foster states that in his own observation the CO_2 has varied from 686 to 1285 grams, and that the oxygen has varied from 594 to 1072 grams, these variations depending largely upon nutrition. The amount of CO_2 that is eliminated is increased by rapid and deep breathing. After a single breath the air is poorer in oxygen and richer in the CO_2; hence, if the breath is held for a long time, there is a pause between the inspiration and the expiration and the CO_2 is increased in the air that is expired. The relative proportions of oxygen taken in and the CO_2 eliminated vary in the proportions between these being represented in what is called a respiratory quotient. This respiratory quotient is found by dividing the variation in the CO_2 by the variation in the oxygen, that is $\frac{4.31}{4.78}$ .901. Hence when a volume of oxygen is lost we find this amount .901 of a volume of the CO_2 gained. This variation is less during sleep. It is greater in middle age persons than in young persons and in old persons. Muscular activity and an increased amount of carbon in the diet will also increase the amount of CO_2 excreted. The principles of ventilation demand a proportion of oxygen to CO_2 that is the reason why the Physiologists have estimated this respiratory quotient so as to have an adequate foundation for the principles of lung ventilation. When a number of persons placed in a limited space with little or no ventilation the oxygen is diminished and the CO_2 is increased also the aqueous vapor and the organic substances are increased. If an animal is placed in a limited space without any air renewal the air gradually loses its oxygen and becomes more fully charged with CO_2 If the proportion of oxygen does

not fall below 15 per cent the respiration remains normal. From 15 to 7 percent the respiration is liable to become labored, inspiration and expiration. From 7 per cent to 4 per cent it becomes very difficult. If it falls under four per cent it is liable to result in asphyxia. When the body dies the blood contains oxygen and this oxygen is absorbed into the tissues of the body. The quickness of asphyxia proving fatal depends upon the amount of oxygen in the limited spaee in which the animal lives. When an animal, for example, is placed in a confined space the animal accommodates itself to the limited amount of oxygen and it will live in an atmosphere so saturated with CO_2 as to cause the immediate death of another animal put in the same chamber. Claud Bernard, for example, placed a bird under a glass globe and a few hours later he put into the same globe another bird; the second animal died in a few minutes in convulsions while the first animal survived for several hours and continued to respire. In addition to the absence of oxygen we must remember the presence of CO_2.

Air that is suitable for breathing should not contain more than .07 per cent of CO_2. Other gases are given out from the body which give to the atmosphere what is commonly called the stuffy character arising from the lack of ventilation. This vitiation is increased where coal oil or gas is used causing the oxygen to be consumed and also filling the air with many the dangerous products of combustion. Difference of opinion exists as to the nature and action of the toxic substances in vitiated air, depending to some extent upon the place, the persons and their circumstances, which are individual to the person or to the place in which the person is found. In addition to the CO_2, expired air contains, as we have said, other substances which render the air impure. Small quantities of ammonia have been found even in the air taken directly from the air passages. By condensing the expired air into a cooling receiver the aqueous vapor has been found to contain organic substances, which by the presence of micro-organisms from the air inspired, causes organic decomposition. These substances in this condition produce in part the odor of the breath. Some of these substances are poisons, either on account of some poisonous substance directly in the air expired or on account of the decomposition of organic matter. The expired air is sometimes found to contain ptomaines. The presence of these poisous substances make the air very injurious to the system. This poisoned air is due more to these substances than to the presence of CO_2, these matters accompanying the CO_2 and being usually measured by the proportion of CO_2 found. Hence, the problem of lung ventilation is not only one of providing for sufficient fresh oxygen or that it be comparatively pure, but also the providing air comparatively free from CO_2 and accompanying organic substances which constitute the impurities of the air for breathing purposes.

The object of ventillation is not only to introduce fresh air, but to dilute the CO_2 so as to restore it to its normal condition. It is estimated that for an efficient ventillation, taking into account the size of the person and size of the room and the activity of the person, supposing that an individual gives off 900 grams of CO_2 daily and that CO_2 is kept at the avererage of .07 volumes per cent, 2,000 cubic feet of fresh air should be supplied for each individual per hour. Pure air contains 4-10 volume in a thousand. If it contains one volume per thousand it is impure and gives off an odor. In cases of muscular activity more than this would be required on account of the increased elimination of CO_2. When persons are limited to certain apartments every person should have a thousand cubic feet of

space, and the floor-room should be at least 1-10 of this and fresh air should be introduced hourly. In the case of large rooms where a number of persons meet, for example, lecture rooms, this renewal of air should be very frequent. The lung capacity represents the total amount of air that can be forced into the lungs by the most forced inspiration. The bronchial capacity is the capacity of the bronchi and trachea, estimated about 8½ cubic inches.

Alveolar capacity represents the amount of air that can be accommodated in the small air passages, the alveoli being smaller during expiration than during inspiration. During normal expiration it is about 120 cubic inches, and during normal inspiration about 150 cubic inches. These are distinguished from the vital capacity which represents the quantity of air that can be expired by the most powerful expiration.

The ventillation of the lungs artificially is of considerable importance. The trachea is exposed and a tube inserted into it through which air is forced periodically into the lungs by the use of bellows or the pump. Some instruments not only cause air to be inspired but alternately to be expired from the lungs. The periodic inspiration is called positive ventillation. The expiration is called negative ventillation and the two processes alternated compound ventillation. In the human subject these methods are very dangerous as the continuance of positive ventillation produces cerebral anæmia, fall of blood pressure and body heat. Hall and Sylvester have described the most commonly adopted methods. Hall's method is to put the patient on his face, supporting the chest upon a pillow, then turning the body gently a little beyond the side position then quickly turning the body on the face, repeating this process about fifteen times per minute. Raising the body on the chest the air is expired ; when the body is raised on its side the air is inspired freely. At each turn of the body upon the face, pressure is brought to bear upon the back below the shoulder blades, the pressure being removed before turning the body again on its side. According to Sylvester's plan the patient is placed upon his back on a solid flat surface with the head inclined slightly downward and the feet upwards, a pillow or small support being placed beneath the shoulder blades. The tongue is then pulled forward beyond the lips and by the use of an elastic band around the chin and elongated tongue it is kept in this position. From above the patient's head the arms are seized just above the elbows, and are then drawn gently above the head and kept in this position for 2 or 3 seconds. Then the arms are turned and pressed closely against the sides of the chest for two or three seconds. These movements are repeated about 15 times in a minute until active respiratory action takes place in the body.

SECTION VII.--Changes in the Blood During Respiration.

As the blood leaves the right ventricle it is venous. When it is brought back to the left auricle it is arterial, of a bright scarlet color. The question that arises, is : "What is the difference between arterial and venous blood?" In passing through the pulmonary capillaries, that is, during pulmonary respiration the blood changes from a dark purple to a bright scarlet color. In other words it loses CO_2 and gains oxygen. In passing through the systemic capillaries in the various tissues of the body, that is, during internal respiration, the reverse process takes place, the blood loses its oxygen and gains CO_2. Hence, the blood changes from a bright scarlet color to a dark purple. The exact nature of these changes in the pulmonary alveoli is not

easily determined. It would seem, however, that the pulmonary epithelium does not perform any particular function of absorption or excretion in this process and that the interchanges between the gases of the blood and the gases contained in the pulmonary alveoli is determined simply by the law of partial pressure. Oxygen passes from the air cells into the blood because the tension of the oxygen in the former is greater than the tension in the latter, that is, the blood which reaches the lungs through the pulmonary artery, while the tension of the CO_2 in the blood is greater than the tension of the gases in the air-cells. Oxygen is passing into the blood both in inspiration and expiration, especially during inspiration. CO_2 is also escaping from the blood in inspiration and in calm expiration, but not in deep expiration. The venous blood becomes arterial if it is exposed to the atmosphere or if it is mixed with oxygen, whereas arterial blood will become venous if it is kept in a closed vessel or subjected to a current of nitrogen or of hydrogen. The chief difference therefore, between the venous blood and the arterial blood is in the amount of oxygen and the amount of CO_2 contained in each. The other differences depend upon this main difference. The ordinary air pump is not sufficient to extract the gas from the blood.

Pfluger has invented a mercurial pump which is a convenient arrangement for the extraction of the gases from the blood. This pump consists of a long barometric tube, the upper part of it opening into a mercurial globe with the upper end of which there are connected two tubes, the one tube vertical and the other tube horizontal—the vertical tube communicating with the air and the horizontal tube opening into a glass receiver in which the blood is placed. At the openings of these two tubes into the globe there are stopcocks.

From the lower end of the barometric tube a rubber tube passes into another globe of larger capacity than the first globe. This larger globe may be raised and lowered by means of a crank arrangement, the object of this arrangement being to extract the air out of the blood that is in the receiver very rapidly. After the air has been removed the blood is put into the receiver, out of which the air has been removed. The blood gases under a minimum pressure then escapes. These gases pass into the small globe from which they are driven through the vertical tube and then gathered in the graduated tubes. By means of this graduation the amount of gas per volume of blood is easily measured. The total amount of gas being found the amount of each gas may be easily estimated by means of volumetric analysis. The percentage of the gases obtained from the two kinds of blood measured at 0°C and 760 mm. of mercury barometric pressure are found to be as follows:

In 100 volumes of blood.—In the arterial blood we find 20 per cent of oxygen, 39 to 40 per cent of CO_2 and 1 to 2 per cent of nitrogen. In the venous blood, 8 to 12 per cent of oxygen, 46 per cent of CO_2 and 1 to 2 per cent of nitrogen. That is, the variation between the venous blood and the arterial blood is wholly in the O and the CO_2, the nitrogen is invariable. This means that arterial blood as compared with venous blood contains from 8 to 12 per cent more of oxygen and about 6 per cent less of CO_2. Some Physiologists say, 8 per cent less of CO_2 In the case of arterial blood there is very little variation throughout the arterial system, while in the venous blood differences occur according to the location of the blood vessels. For example, venous blood from an active secretory gland is almost identical with the arterial blood, while if the gland is inactive the blood is characteristically venous.

Lavoisier, found that respiration consisted of the combustion of carbon and of hydrogen, the blood furnishing the combustion materials and the air furnishing the oxygen. He admitted, however, that CO_2 is formed directly in the ~~lungs, or even~~ in the blood vessels wherever the oxygen can come into contact with the carbon found in the blood. His successor, Lagrange, believed that oxygen is dissolved in the blood combining with carbon and hydrogen to form CO_2 and H_2O. These are liberated, the CO_2 and H_2O—in the lungs, but the CO_2 production does not depend upon the oxygen, that is, the oxygen that is supplied by or in the lungs. If an animal, for example, is placed in a chamber with nitrogen or hydrogen in place of the atmosphere, the CO_2 is produced to the same extent as in the normal atmosphere. The CO_2 also is found in the body, this CO_2 being supposed by some Physiologists to be stored in the capillaries, and from these capillaries to be passed into the lungs.

Two theories of respiration have been advanced by Physiologists in recent years, to account for the interchanges between the blood and the air. 1st, the combustion theory. This theory ascribes to the process of combustion in the lungs the production of the CO_2 and H_2O aqueous vapor; and 2d, the secretory theory. This theory denies that there is any combustion process in respiration, whereas, the oxygen becomes absorbed in the lungs and then becomes diffused through the other tissues of the body, the CO_2 being secreted in these, absorbed into the blood and then carried to the lungs and given off in the expired air. Recent investigations in connection with the gases of the blood and the temperature of the blood as found in the right and left sides of the heart have given predominance to the last theory which now prevails in the field of Physiology. The older Physiologists rejected the secretory theory on account of the fact that no proof existed of free oxygen or free CO_2 in the blood. The same obstacles met those who defended the secretory theory because if the process of interchange takes place in the blood then certain free gases must be found in the blood. And hence, so long as the gases of the blood remained unknown the combustion theory prevailed. Priestly in the 17th century 1st emphasized the change in color of the blood as being due to oxygen from the air, the blood becoming purple under the influence of CO_2. Magnus in the beginning of the 19th century invented a mercurial air pump by the use of which he could exhaust a receiver so that introducing the blood into the vacuum CO_2, O and N. could be liberated from the blood. To him we are indebted for our systematic knowledge of the gases of the blood and he is really the founder of the secretory theory of respiration. Gaseous masses unlike the solid and the fluid masses have no form hence gases are said to be formless. These gaseous masses consist of a large number of molecules always tending to separate from one another on account of mutual repulsions. Hence, if two gases meet they will easily intermingle until an exact quantity of each gas enters into the combination. The molecular repulsion is called the gas pressure or the gas tension. The physical law bearing upon gas is that the greater the molecules the greater the tension. Hence the law of gases is that the pressure is in inverse proportion to the volume. If two gases are suspended or separated from one another by a slight membrane, they will mix, passing through the membrane with a speed in proportion to the density of the gases. The fluids also absorb the gases. For example, if some amonia gas is placed in contact with water, the water wlll rapidly absorb the amonia gas.

The higher the temperature of the water is raised, the fluid absorbs less

of the gas, and when the fluid reaches boiling point no gas is absorbed, the cause of this being that the fluid becomes gas. The co-efficient of absorption in the case of a fluid for a gas is, according to Bunsen, the number representing the gas volume reduced to 0°C and at 760 mm. Barometric pressure taken up by one volume of the fluid. The volume of gas, then, that is absorbed does not depend upon the pressure but the weight of the gas absorbed rises and falls in proportion to the pressure. If an atmosphere above a fluid consists of two or more gases, absorption will take place in proportion to the pressure each gas would have if alone, in the place of the mixed gases. This pressure in the case of two or more gases is called the partial pressure of gas, according to Bunsen. The partial pressure, therefore, depends upon the volume of each gas in the combination of gases. Each gas forming an element in a mixture exerts a pressure equal to its proportion of the mixture. For example, atmospheric gas is under the pressure of 760 mm. In air we find 20 volumes per cent of O. and N. 79 volumes per cent; therefore, the partial pressure of O would be 760 times 20.81 divided by 100, this would equal 158.16 mm. represent the partial pressure of O. In the same way, the partial pressure of N. would be 760 times 79 divided by 100 representing about 600.04 mm. of mercury. The partial pressure CO_2 would be found in the same way, 760 times .04 divided by 100 would give us about .304 as the partial pressure of CO_2. If above a fluid containing a gas like CO_2 there is another gas, say the atmospheric gas, as CO_2 is very small in the atmosphere, its tension is O, the CO_2 will escape from the fluid until there is an equilibrium between the CO_2 in the fluid and in the air, that is, till CO_2 tension in the air is equal to CO_2 tension in the fluid. This tension of the gas represents what we call partial pressure represented in mm. of mercury, a tension exerted by the gas of the atmosphere when there is no diffusion between the gas in the fluid and the gas in the atmosphere. By using these results in connection with arterial and venous blood we find (1) that both kinds of blood contain O, CO_2 and N. (2) the difference between arterial and venous blood is in the amount of O and CO_2, (3) the gases are dissolved in the blood so that respiration is simply a process of diffusion, CO_2 passing out and O passing in according to the law of pressure. Three important elements enter into the process of respiration, (1) the inspiratory and expiratory movements causing a partial mixture of the air, (2) subsidiary movements such as the heart pulsations and (3) the diffusion of O and CO_2 depending upon the law of partial pressure. The venous blood containing CO_2 at blood temperature and with a certain pressure enters the pulmonary capillaries distributed over the walls of the alveoli in the lungs. These air cells are filled with air at a certain pressure and temperature. If the pressure of CO_2 in the blood is greater than that of CO_2 in the air vescicles, CO_2 will pass from the blood till equilibrium is restored. Similarly if the pressure of O in the blood is greater than that in the air cells O will be absorbed until equilibrium is produced. This is true if the gases are simply dissolved in the blood. But the gases exist, as Liebig pointed out, in the blood rather in a state of loose chemical combination, dissolution taking place by lessening the pressure in the vacuum or by other gases. As a result, the amount of oxygen absorbed does not vary exactly with the pressure but decreases in the case of temperatures below the atmospheric pressure and increases in pressures above atmospheric pressure.

This fact is proved by the observation that blood serum does not absorb much more oxygen than does water, (blood at 30° C containing only 2 vol-

umes per cent of O, if the O is dissolved in the fluid,) and defibrinated blood absorbs oxygen, the amount depending not upon the pressure but upon the amount of the pure haemoglobin that is found in connection with the blood. In the same way CO_2 is in a state of loose chemical combination, only a small quantity being subject to the law of partial pressure. This, of course, would be explained on the secretory theory, that the pulmonary membrane is actively engaged in the secretory process. The gases of the blood, in this case, instead of existing in a simple solution, are largely in combination with the blood so that its escape from the blood is by a process of dissociation. Berzelius has shown that 100 volumes of water absorbed at a given temperature and pressure three volumes of oxygen. 100 volumes of blood serum absorbs 3 1-10 volumes of oxygen, and 100 volumes of blood will absorb 9 6-10 volumes of oxygen. There must be, therefore, something in the blood which assists or causes the absorption of such a proportion of oxygen. The haemoglobin has been found to play an important part in respiration, and as we will see later, this haemaglobin is the element in the blood which absorbs oxygen according to the law of partial pressure. The coloring matter of the blood is found to exist in two states, the differences being represented by difference in color. These two states represent differences in oxidation. This is found in connection with the spectroscope. Only a small quantity of O is absorbed according to the law of partial pressure, the great mass of oxygen being in combination with the haemoglobin. On the other hand the CO_2 seems to be associated with some substances in the blood plasma and that its dissociation is connected with some substance in the red corpuscles. The haemoglobin when it is united with oxygen is called Oxyhæmoglobin. Hæmoglobin is an amorphous powder, or crystal line, very soluble in water. Crystallized hæmoglobin readily absorbs and holds in combination a quantity of oxygen equal to that found in a volume of blood containing the same amount of hæmoglobin. This gives us, then, a special function for the red corpuscles of the blood in connection with respiration. The hæmoglobin of the blood in the pulmonary artery absorbs oxygen, becoming oxyhæmoglobin, carrying it to the tissues where the oxyhæmoglobin is reduced. Thus the coloring matters of the red corpuscles are constantly carrying the oxygen from the lungs to the tissues, the association and the dissociation taking place without destroying the hæmoglobin. In regard to the CO_2 our knowledge is less definite. The greater part of the CO_2 is found in the blood plasma. Defibrinated blood, for example, yields only a little more CO_2 than the serum of the blood to the same amount. Blood serum in a vacuum yields about 30 volumes per cent of CO_2. If a mineral organic acid is added to the serum the per cent will be very small, amounting only to about 6 volumes per cent. Defibrinated blood, on the other hand, will yield 40 volumes per cent of the CO_2 the yield of a little more CO_2 from the same amount of defibrinated blood than in the case of the blood serum, being supposed to be due to something in the defibrinated blood which acts the part of an acid. There must be some chemical substances for the absorption of the CO_2 of the blood. Some Physiologists have suggested plasma albumin. As yet, however, this subject is not fully investigated by the Physiologists so that we can say definitely what substance causes or produces this absorption. In all probability what takes place is as follows:

The air inspired is in some way separated in the air cells of the lungs, by the fine epithelial cells and the endothelial cells of the pulmonary capillaries from blood circulating in them. This interchange is through a fine

porous membrane. The oxygen, as we have said, is loosely bound to the hæmoglobin of the corpuscles; hence, the law of diffusion applies only in so far as it must pass into the plasma of the blood so as to reach the corpuscles. The corpuscles of the venous blood return from the tissues with reduced hæmoglobin. Oxygen enters the plasma from the air and the hæmoglobin at once takes up a fresh supply of this oxygen. If the oxygen were not loosly combined with the hæmoglobin, the oxygen alone would be absorbed, and the amount that is absorbed would depend upon barometric pressure at the time, varying at different times with the variation in the pressure, and only with the variation of the pressure. If this is true, such variation would, materially, interfere with the conditions of health. This is evident from the fact that in high altitudes as well as in deep mines, the health of thn blood is not materially affected, although the pressure rises and falls considerably for the oxygen exists in a loose chemical combination independent of the law of partial pressure. In the case of CO_2 it is found, as we have said before, almost exclusively in the blood plasma, a small part of the CO_2 being absorbed, and a large part chemically bound either with sodium carbouate or with the acid of sodium carbonate and sodium phosphate. In the air CO_2 is found only in small traces. The air of the lungs is never wholly expelled, some of the air that is rich in the CO_2 always remaining in the lungs. Hence, the mixture of the inspired air with the air of the air vescicles makes the latter air rich in oxygen and poor in the CO_2., although there is more CO_2 than in atmospheric air.

The pressure of CO_2 in the venous blood is found to be almost 50 per cent more than that of the air cells. CO_2 then passes from the blood into those air cells till equilibrium is attained. Before this is attained, however, expiration begins and expiration has driven out a portion of the air so that the pressure of the CO_2 again becomes less than the blood. During expiration and the pause following it, still further elimination of CO_2 takes place. In expiration, then all the air is not driven out of the lungs for if it was so then no diffusion could take place during expiration and the pause following it, Diffusion could only be possible during inspiration. The separation of the CO_2 in this case from the pulmonary blood would be incomplete, changes being found only in the rapidity of the process which would materially interfere with the respiratory changes in connection with the blood necessary to carry on the normal process of respiration.

Having discussed these changes that take place in connection with the gases of the blood it is necessary now to inquire what are the causes of the changes that we have observed. The absorption by oxygen of the blood, as we have said, does not follow the physical law of simple absorption on the basis of pressure. It is suggested, as we have said, that oxygen is in combination with some substance in the blood, which retains its association when pressure is lowered until a certain point is reached, when dissociation takes place, no appreciable dissociation taking place till this point is reached. After this point is reached dissociation takes place very rapidly. We have seen that the substance with which the oxygen is closely associated is the hæmoglobin of the red corpuscles. Hæmoglobin when dissociated from other substances is an amorphous powder or a crystal in solution. The peculiar relation between the hæmoglobin and the stroma in the normal blood prevents the hæmoglobin from being dissolved in the serum. In order to get the hæmoglobin this relation between the stroma and hæmoglobin must be broken. By the addition of distilled water or ether, or chloroform, the blood will be rendered lakey. By the removal of the alkaline serum the

hæmoglobin is given up in the solution. If dilute acetic acid be then added the alkaline reaction is reduced, and if alcohol is then added to the solution to the extent of one-fourth of the solution and if the solution be apart at 0° C the hæmoglobin in the solution will be crystalized. These crystals bsing separated by the process of filtration. These crystals vary in the case of the blood of different animals. These hæmoglobin crystals are said to contain, for example, in the case of the dog's blood of C 53.85, O 21.84, N. 16.17, H. 7.32, S. .39, and iron .43. Iron is found in small quantities and it is a characteristic element of the hæmoglobin. If these crystals are examined microscopically they are found to possess the bright scarlet hue of arterial blood, in masses they are much darker. If these crystals are placed upon a slide with a few drops of distilled water the same arterial color may still be observed. This same solution placed in front of the spectroscope absorbs some rays of light, two very marked absorption bands being observable. These absorption bands are characteristic marks in the identification of blood. The intensity of the bands depending upon the strength of the crystaline solution. Under the micro-spectroscope the same marked appearances are presented by the crystals of hæmoglobin. If these hæmoglobin crystals are placed in the mercurial pump vacuum there is a change in color and the oxygen is driven off. This indicates that there are two volumes of O in the hæmoglobin, (1) the oxygen found in the molecular composition of hæmoglobin, and (2) a quantity loosely combined with hæmoglobin and therefore easily dissociated under the influence of pressure. If this second quantity of O is dissociated the change of color takes place, the crystals being dark purple in the thick parts and greenish in the thinner parts at the marginal edges. In the case of a solution of hæmoglobin we find the same quantities of O which may be liberated by the low pressure of the air pump or by passing through the solution a stream of hydrogen, resulting in the change of color from the bright scarlet to the deep purple. When this reduced solution of hæmoglobin is examined spectroscopically the two absorption bands formerly seen in the unreduced solution give place to a single absorption band wider and more faint in color, the single band lying about midway between the two bands of the unreduced solution. If this hæemoglobin solution which has been deprived of all the loosely combined O is exposed to theatmosphere, O is at once absorbed. The amount of O absorbed if there is an atmosphere filled with O amounts to the full combination in the hæmoglobin as found in the blood, each gram of hæmoglobin absorbing 1.59 of O. If the full complement is taken up the hæmoglobin changes from the dark purple color to the bright scarlet hue. In these changes we have from the standpoint of physiological physics the explanation in part at least of the changes taking place in the blood in connection with respiration and an explanation of these changes of color in venous and arterial blood. When the venous blood leaves the right ventricle there is too small a proportion of hæmoglobin for the red corpuscles. Hence the dark color of the blood. In ordinary venous blood when examined after dilution under the spectroscope the two characteristic absorption bands are observed. The hæmoglobin is only partly reduced in this condition, there being a quantity of loosly combined O. The venous blood only loses this O after death resulting from asphyxia when the venous blood becomes characteristically venous, the hæmoglobin being reduced and exhibiting the one broad absorption band instead of the two. When the venous blood goes through the lung capillaries it takes up O from the air, the red corpuscles being oxyhæmoglobinized, that is, almost completely saturated with the

O and changing to the bright scarlet color. When the blood goes out from the left ventricle and enters into the tissues through the capillaries this oxyhæmoglobin once more loses its O and again becomes venous, the hæmoglobin being the oxygen carrier. Hence the chief difference between the arterial and venous blood is the presence in the former and the absence in the latter of oxygen in combination with hæmoglobin.

In addition to this there are subsidiary causes that enter into the change. By the swelling of the corpuscles, it loses to a certain extent its power of refraction; hence the number of rays that pass into and are absorbed within it, multiply beyond the number of those that are reflected from the marginal surface. This swollen condition may be due to water or to the presence of CO_2; hence the presence of water or CO_2 tends to increase the venosity of the blood. On the other hand, the presence of salts tends to contract the corpuscles reducing this venous condition. The peculiarity of the eombination of O and haemoglobin is its loose character, that is, the readiness with which the association and dissociation takes place without destroying the integrity of the haemoglobin. The haemoglobin will associate with other gases in the same way. If C O is brought into contact with haemoglobin by causing diffusion, the color is changed to a bluish hue, the association taking place between C O and haemoglobin, although not so freely as with O. C O is sometimes used for this reason, to drive out O from the blood so as to measure the volume of O present in the blood. It is this that makes C O so dangerous when inhaled, driving out the O from the blood, the reduced and unreduced haemoglobin freely associating with C O in the venous blood, producing a bright cherry color in the blood after death. This C O haemoglobin cannot be used in respiration because it cannot absorb O, although it exchanges its C O for O very slowly. This produces death by suffocation on account of the absence of O, the blood not becoming very venous but bright colored on account of the presence of C O. The diffusion of haemoglobin takes place with difficulty on account of its proteid character. Haemoglobin is a colorless proteid associated with a coloring substance, haematin, of a brownish red color. If a solution of haemoglobin is heated, coagulation takes place, the color of the coagulum being brown on account of the presence of haematin. This haematin when freed from combination with globin is a brownish amorphous powder with a bright metallic polish. When iron is extracted under the influence of sulphuric acid it still retains its color but ceases to combine with O, indicating that the iron element is an important constituent of haemoglobin, in the respiratory function, although it is not known what part it plays in respiration.

After the decomposition of blood the hæmoglobin is changed into methæmoglobin, the only difference as yet known being that the O is more stable, being more firmly connected with the molecules. Thus, the conclusion reached in regard to the interchange of O in the blood, is that only a small proportion of the O is absorbed on the basis of the law of partial pressure, the large proportion being in loose combination with the haemoglobin this combination being of such a nature that while O freely unites with the haemoglobin, it also becomes dissociated at a low pressure or by the action of indifferent gases, or under the influence of substances which have a stronger affinity for O than the haemoglobin. In the venous blood the haemoglobin is reduced while in arterial blood, the haemoglobin has a large proportion of O in combination with it, the purple color of reduced haemoglobin giving to the venous blood its dark hue, and the scarlet color

of oxyhaemoglobin to the arterial blood its bright scarlet color. The CO_2 in the blood depends upon other circumstances not so clearly understood. The CO_2 does not depend upon the law of pressure, and it is not simply dissolved in the blood; it is in association with some substances and can only be liberated by dissocation. It seems to be more largely in the blood plasma than in association with the red corpuscles. If blood serum be passed through the mercurial pump, a large proportion of CO_2 is given off. This is called the loose CO_2. If an acid is used, an additional quantity of CO_2 will be given off from the solution called fixed CO_2. If a volume of blood is passed through the mercurial pump all the CO_2 will be given off, indicating that all the CO_2 in the blood normally is in loose combination, loosely associated with some substance in the blood plasma, the substance itself being unknown.

In the case of O we find not only the haemoglobin in individual molecules, but collected in masses and bound up in the corpuscles. The haemoglobin is separated from the air in the alveoli by the plasma and the membrane of the capillary and alveolar walls, corpuscle being separated from corpuscle, and therefore the haemoglobin in each corpuscle is separated by a plasma layer through which the O must pass in order to reach the haemoglobin.

Each corpuscle occupies a certain area in the plasma, the pressure of the air in the alveoli and in the plasmic solution, and the amount of O in the hæmoglobin determing the interchange between the air and the blood. The plasma acts very much like the water solution in regard to the absorption and elimination of O, the membrane of the capillary and alveoli wall being kept moistened by the lymph so that the living membrane under the influence of moisture assists in the gaseous diffusion. Under the influence of a reduced pressure arterial blood ceases to take up O. This point in the reduction of pressure is represented as below the 300 mm barometric pressure mark, that is, when the reduction of O in the atmosphere amounts to more than one half, atmospheric pressure being 760 mm B. M. If the O of the air is gradually reduced after the O falls below 10 per cent of the atmosphere dyspnoea follows; hence, it is said that at 17,000 feet above the normal level of the atmosphere, the atmospheric pressure is reduced to about 300 mm and the partial oxygen pressure is such that venous blood is unable to take up oxygen sufficient to convert it into arterial blood, resulting in considerable difficulty in breathing,

In the case of CO_2 it would seem that there is a diffusion from the blood in the minute capillaries surrounding the alveoli into the air in the alveoli. In order to this the pressure in the pulmonary artery must be always greater than the pressure in the pulmonary vein. The alveolar pressure of CO_2 is very difficult to estimate because the CO_2 comes from the blood into the alveoli. The experiments seem to indicate that the passage of the CO_2 from the blood into the alveoli takes place by diffusion. If a catheter surrounded by a small sac is injected into the bronchus of a dog so that by inflating the sac the bronchus can be occluded, in this way the entrance of fresh air can be stopped while a sample of the air in this portion of the lung can be taken out by the catheter and analyzed to discover the amount of CO_2. In this way it is found that the physical loss of diffusion explains the passage of CO_2 from the pulmonary capillaries into the pulmonary alveoli. In the mixing of air in the lung, the first force brought into play is the principle of diffusion depending upon the partial pressure at the different points on the respiratory system. The differences in the partial pressure depend

upon the estimates we have already given. Knowing the composition of the mixed gases the partial pressure is easily estimated, each gas constituting an element of the combination exerting a partial pressure equivalent to its proportion of the combination. The first part of air expired contains a large proportion of inspired air and a small amount of air found in the respiratory passages preceding inspiration.

As the process of inspiration advances, more of the vitiated air comes from the lower respiratories, and less of the inspired air enters into the combination, the last of the expired air being almost wholly air from the lung alveoli. O is constantly being diffused from the upper respiratories to the smaller air passages and the alveoli, in other words from greater pressure to lesser pressure. Equilibrium cannot be established because freshly inspired air is constantly entering and after entering the lungs is constantly passing into the blood. The CO_2 is also constantly being diffused under the influence of pressure, the CO_2 passing from the blood to the alveoli, increasing the volume of CO_2 in the lungs and causing the passage from greater pressure to lesser pressure, the CO_2 being diffused from the lungs outwards. Secondly, the mixture of air in the lungs takes place under the influence of the tidal waves of inspiration and expiration, an air force pressure which causes partial diffusion of the gases. In the upper respiratories there is little difference between the gases in the air and the gases in the respiratories. At each respiration a fresh volume of air is introduced and about 3-5 of this volume is carried to the lungs while during expiration a similar volume of vitiated air passes from the lungs into the upper respiratories. In this way there is a tidal current that assists in promoting the diffusion of the gases. Thirdly, the cardiac pulsations exert a similar influence. At each heart beat there is set up a movement of the gases which tends to promote diffusion. This force plays a very important part in the continuation of respiration during suspended animation and in the case of the hybernating animals. Thus, it is impossible to account for the diffusion of the gases on the principles of diffusion alone. Physical and mechanical forces diffuse the O to the plasma where it comes into association with haemoglobin. On chemical principles the union of O and heamoglobin takes place at a low pressure. In addition to this the tissues of the luugs act as a secretory membrane, thus assisting in the process of diffusion. This is equally true of O and CO_2 although the evidence in favor of it so far is not entirely conclusive.

SECTION VIII—The Respiratory Changes in Connection with the Tissues

What takes place in the pulmonary capillaries in connection with the air cells also happens in connection with the systemic capillaries, the fluid transuding through the capillary walls and bathing the entire tissues, the O passing into this fluid and also, of course, collecting the CO_2 from the tissues and passing this into the blood. The only difference in connection with the tissues is that the comparative tension or pressure of the O and the CO_2 within the vessels and without the vessels in the tissues is found to be just the reverse of those found in conneetion with the lungs; the tension of the gases in the fluid being greater than the tension of the gases in the tissues. The tension of the O in the tissues is extremely low for this gas, that is the O, does not remain free in the tissues, but the O at once enters into combination with the tissue element and with some substance or substances found in connection with those tissues becoming a part of the tissue substance itself. Hence, the tension of the O in the blood is much greater

than the tension of the O in the tissues and this gas, therefore, freely escapes from the blood into the tissues. During the active contraction of the muscle, the protoplasmic substance passes through rapid decomposition changes, including the formation of CO_2. On the other hand, the tension of CO_2 in the tissues is greater than the tension of the CO_2 in the arterial blood. Consequently CO_2 passes from the tissues into the blood changing the blood from a bright scarlet to a venous color or a deep purple. The pressure of the CO_2 in the lymph is also less than the pressure of the CO_2 in the venous blood. It seems difficult to understand that this is so, how the venous blood can absorb the CO_2. The lymph, however, has modified its pressure by contact with arterial blood, both in the tissues and in the lymphatics. The pressure of the CO_2 in the tissues is estimated at 45 mm. and the pressure of the CO_2 in the venous blood is estimated at 41 mm. of mercury. The CO_2 that is thus set free is then absorbed by the blood loosely combining with the carbonates and phosphates found in the blood. The blood thus represents the medium of respiration containing within it the gases in solution. This has an important bearing upon breathing in connection with the tissues. It was first found that the tissues of the body as well as the fluids and the skin took up O and gave out the CO_2. Liebig was the first to point out that fresh muscle used up O and gave out CO_2 depending, to a large extent, upon the blood supply found in the muscles. This was followed by the observation of other Physiologists who found that the contraction of muscles used up a large amount of O and eliminated a larger amount of CO_2 than the muscles which are inactive. Muscle is thus found to possess a great absorption power for the O. In this way we find that the entire body takes part in respiration and not as was at first supposed simply the respiratory system. The O is breathed in, not only through the regular respiratory system, but also in connection with the skin; the CO_2 is eliminated in the same way. The O breathed into the body by respiration is breathed into the tissues. This respiration is subsidiary, and yet it has an important bearing upon the respiration of certain animals especially when these animals are placed in certain media. Respiration thus, presents many interesting features aside from the question of the simple introduction of air into the lungs. The question of the proportion of O absorbed to the CO_2 produced requires to be solved. In the case of the human subject the respiratory quotient is found as we have said, by dividing the variation of the CO_2 by the variation in the O, giving us a respiratory quotient of .87 varying to .75. This variation of the respiratory quotient in connection with the tissues depends upon the nature of the diet, depending largely upon the amount of carbohydrate substance found in the food. In the case of animals that are deprived of food, the respiratory quotient is represented as .75, indicating that the combustion takes place at the expense of the body substance in the case of a starving animal. The respiratory activity varies in the different animals, the general rule being that the smaller the animal, the higher the degree of its respiration. This, however, is only true to a limited extent. For example, a small singing canary requires 12 or 13 times as much O as a common fowl. In the case of a frog, it can live in an atmosphere containing one 150th part of the O necessary for the life of the canary. The fishes, like the frogs require only a very small quantity of O, the gases of the sea water being found in very small quantities. By a system of storage however, these animals—the fishes—can extract from the water the O and thus provide for themselves, a sufficient supply of O for a considerable period of time.

THE RESPIRATORY CHANGES IN CONNECTION WITH THE TISSUES.

The importance of tissue respiration is evident from the fact that the chief chemical changes of the body take place in connection with those tissues. The same is true of the decomposition changes which result in the formation of the CO_2. The tissues have a strong affinity for O so that a very low pressure is sufficient for the absorption of a large proportion of the O. The tissues from this standpoint represent an aggregation of cells, each cell absorbing O and excreting CO_2. The cell activity depends upon the amount of O that is absorbed and the degree of oxidation in connection with the O absorption. Experiments have been made by Physiologists in connection with the different tissues of the body. For example, it is found that 100 grams at a temperatnre of 38°C, give the following results in connection with the different parts of the body. In ordinary muscles 23 C. C. in heart muscles 21 C. C., in the brain 12 C. C., in the liver and kidney 10 C. C., in the spleen 8 C. C. and in the lungs 7½ C. C. In the case of all these tissues, CO_2 is formed directly in proportion to the volume of O absorbed. The blood of the body as it circulates, carries the O to the tissues and it also discharges the function of disintegration and oxidation. 100 grams of blood for example, at 38°C absorb 8-10 of one cubic centimeter of O and produced the same volume of CO_2. In addition to this the blood bears partially oxidized substances from the tissues to the lungs. In the case of the muscles, when resting at normal temperature, the O absorbed is larger than the CO_2 eliminated, while, during the activity of muscles, more CO_2 is produced than the amount of O that is absorbed. This, however, is not fully tested as yet. The question now arises, "How do these processes take place and where does this process take place, in the blood, or does it take place in the tissues?" There are certain oxidizable substances in the blood and the blood has has a power of oxidation but when the blood is taken from the body this power of oxidation is found to be very small. We must take into account this fact, that this may be due to a certain extent to the fact of the removal of the blood from the body. In the case of the muscle of the frog, for example, extirpated from the body no free O is found by subjecting the muscle to the mercurial air pump; while resting muscle produces O and also CO_2, even when no O can be obtained from the outside of the muscles. O is necessary for the maintenance of life and also for the maintenance of muscle irritability, although it is not necessary for the manifestation of that irritability. As we find, muscles will continue to exhibit irritability in an atmosphere charged with H or with N. Muscle, therefore, must have the power of absorbing O and also the power of storing O in its substance, so that the O thus stored can be used when required in the oxidation processes. At the same time there is a constant oxidation process going on in which case this stored up O supplies the necessary materials for the oxidation process. Muscles, like other body substances, are constantly passing through two changes, these being represented by the anabolic process and the katabolic process. During these processes the O is combined in some way with carbon. In what way this combination takes place in the muscular metabolism is not known, but that it does take place is well known.

As the presence of O in the muscles has nothing to do with the interchange, there must be a constant passage of O from the blood to the tissues, or from the red corpuscles through the plasma, the capillary walls of the lymph to the tissues. As the CO_2 is produced, CO_2 pressure or tension will force the CO_2 from the muscles through the lymph spaces, through the lymph, through the capillary walls into the blood plasma. Thus there is constantly going on, a double interchange between the blood and the tis-

sues. In all the other body tissues, similar interchanges are found to take place, free O being absent from the tissues, the lymph and the plasma, whereas, CO_2 is present in abundance, in the tissues, in the lymph and in the blood plasma. Thus we conclude that when the O is carried to the tissues by the arterial blood, the pressure of the blood drives it into the tissues all the O thus passed into the tissues being stored away in some way in connection with the tissues, the combination being so stable that no free O exists in the tissues. In the same way by the continued activity of the muscles, CO_2 is produced, and this under the high pressure found in the tissues, is passed into the blood so that the venous blood with a high pressure of CO_2 passes out of the tissues into the venous circulation and finally into the lungs.

A subsidiary form of respiration is found to take place through the skin. In the case of the frog, for example, the skin, is the principal organ of respiration, death being produced from suffocation more rapidly in the case of the frog covering the skin over with an oily or greasy substance to prevent this cutaneous respiratiou than by compressing or ligaturing the trachae. By the extirpation of the frog's lung it is found that the amount of O absorbed, and the amount of CO_2 eliminated does not diminish at all or only to a very slight extent. In the human subject, on the other hand, the skin is only in a very subsidiary sense, an organ of respiration, the amount of air, as we said before, being about one 140th part of the entire volume of air absorbed in the form of O and excreted in the form of CO_2. The ratio representing the relation of lung absorption or elimination to skin absorption or elimination is placed as follows: In the case of O it is 1 to 100 or 200; in the case of CO_2 it is 1 to 250, giving normally about 1-150th , or a little more; in the case of cutaneous respiration the moisture of the skin freely assists the respiration and also the higher temperature of the external atmosphere.

SECTION IX.—Abnormal Respiration.

Pure air at the ordinary pressure and with the ordinary composition is necessary to normal respiration. In order to estimate the abnormal conditions of respiration it is necessary that we know the normal conditions and the normal quantities of gases used in respiration. The average quantity of O absorbed daily by an average adult is estimated about 700 grams varying up to 1100. Of the CO_2 it is estimated that in 24 hours an adult exhales from 700 to 1300 grams, the average being about 900. The amount of CO_2 however, exhaled depends upon the number of circumstances. 1st. It depends upon the number and the depth of the respirations. The amount of CO_2 is increased by increasing the number of respirations and also by increasing the depth of the respirations. Normal breathing expires 4.38 per cent at each expiration. In deep and slow expiration, on the other hand, this is increased to 5 per cent. 2d. The amount of the CO_2 depends upon the extent of the pause. In the case of a single expiration as the expiration advances the amount of CO_2 increases. If the pause is lessened more CO_2 is exhaled as the process of eliminating CO_2 from the blood goes on during the whole period of respiration including the pause. Thus, by lengthening the pause the amount of CO_2 accumulating in the lungs is increased, causing the expired air to be much richer in the CO_2. 3d. A number of minor causes also influence the amount of CO_2. For example, increased muscular activity increases the production of CO_2. An increase also in the body temperature increases the amout of CO_2 and vice versa.

The kind of food taken also affects the amount an increase, for example, in the carbon from the use of carbohydrates and vegetables increasing the production of CO_2. 4th. A number of circumstances tend to lessen the production of CO_2. During sleep, for example, CO_2 is lessened sometimes to a consideration extent. The deprivation of food has also a similar effect, the diminution reaching a minimum. The rapid lowering of atmospheric pressure produces in the lung capillaries an air bubble condition resulting in the diminution of CO_2 and very soon in fatal results. The body mechanism is designed to work under a normal pressure, varying from 760 mm. B. M. to about 500 mm. This represents an altitude of from sea level to 6000 or 7000 feet above the sea level. If there is any great change either of increase or decrease in the pressure it affects the entrance of O and the exit of the CO_2 and it also affects the process of the body, both chemical and physical. If an animal is placed in an air in which the pressure is greatly diminished as for example. in an air receiver out of which the air has been exausted, convulsions follow the gas freed from the blood inside the vessels, obstructing the circulation and also interfering with the cardiac movement. In fact any sudden lowering of pressure completely unbalances the entire vascular and respiratory systems. This unbalancing causes the feeling of distress that is associated with sudden change of pressure. This produces, in the case of the sudden lowering of pressure, the conditions which differ from asphyxia, namely muscular debility and paralysis due to the lack of nervous stimulation. In the case of the increase of atmospheric pressure where the increase is above a certain point the signs are a sleepy condition or an unconscious feeling similar to that which is produced in the case, for example, of narcotic poisoning due to the depression of the system. When the pressure rises to 15 atmospheres of air in this case we have 3 atmospheres of O, we will find convulsions and asphyxia taking place identical with the results found in connection with deficiency of O, the CO_2 production being decreased correspondingly and death resulting from asphyxia. Expired air always contains slightly more N than inspired air, the N being derived not only from the air that is inspired but also from the nitrogenous matters used as food, about 7 to 8 grams of N being eliminated from the system in 24 hours. In the case of H_2O it is estimated that about 300 grams are excreted from the lungs daily, this being taken from the blood and from the vapor in the air that has been inspired, the amount varying somewhat, according to the character of the air inspired, the depth of the respiration and also the duration of the respiratory period.

The respiratory mechanism can adapt itself to abnormal conditions within certain limits. Certain gases modify the respiratory actions and in some cases, suspend respiration altogether. Nitrogen or hydrogen may be breathed without any dangerous results i f a sufficient amount of O is present. Pure nitrogen and hydrogen when breathed quickly, prove fatal for lack of O. They may be inhaled without dangerous results if they contain 12 or 13 percent of O. Such gases as hydrocloric acid, sulphurous nitric acid and ammonia gas cannot be inspired because they result in spasmodic closure of the glottis, producing at the same time irritation of the respiratories. Other gases like carbonic acid, carbonic oxide, sulphurretted hydrogen, etc., enter into the lungs and producces dangerous results from interference with the normal respiration or have some poisonous effect on the blood of the tissues. Inspiration of pure CO_2 results fatally in a very short time but 25 to 30 per cent in the air does not prove fatal if not continued for more than a few minutes. Carbon monoxide is a very dangerous and

poisonous gas quickly destroying life when found to the extent of 1 per cent. It combines with haemogloblin so that the haemoglobin is prevented from performing its function in connecton with the carrying of oxygen. The blood under its influence turns into a very bright cherry color; .001 per cent of the air will affect the breathing and it is found that if 60 per cent of the haemoglobin is combind with carbon monoxide the heart's action is effected, respiration is weakened and death gradually ensued. Nitrogen monoxide mixed with O is the ratio of 2 to 1 may be breathed so as to induce intoxication. This is called the laughing gas. If breathed in its purity it results in asphyxia. Sulphurretted hydrogen mixed with the air to the extent of .4 per cent causes the blood to become greenish and results fatally.

Certain expressions are used to denote peculiarities associated with respiration. When the respiration is normal and easy, the amount of O and CO_2 being normal it is called *eupnoea.* Variations from this normal a re expressed as follows: *Apnoca* represents a state in which the respiratory movements are suspended. It may result from quickly repeated inspiration of air in which case the suspension takes place for a few minutes. In the case of artificial respiration, especially in animals subjected to tracheatomy, if the lungs are repeatedly filled artificially with air and then the inflation is stopped, apnoea follows. After a short rest the respirations begin very feebly, and gradually return to the normal. The cause was formerly supposed fo be found in the excessive amount of O in the blood and the lack of CO_2. If the blood becomes saturated with O the respiratory actions will be arrested. If bellows are used to inflate the lungs by diminishing the pause between the successive inflations, the respiration becomes slower and gradually is arrested altogether without arresting the cardiac movements. This is due undoubtedly to the large amount of O present, and the small amounts to CO_2. But this only represents one apnoeic condition. There is a connection between apnoea and the amount of O in the blood, the apnoea being more characteristic after breathing pure O than after breathing pure air, and the apnoea is less characteristic if O is not present in its full complement in the air. The arterial blood of apnoeic animals is hy peroxygenated. From this it is concluded that the blood is overcharged with O and that breathing is suspended till the O is exhausted or until CO_2 is produced sufficient to arouse respiratory activity. That there is something in this cause is apparent for the fact that by respiring pure O it becomes more marked than in respiring the pure air. To answer this it has been shown that by filling the lungs with pure hydrogen, apnoea may be produced, but not of such a marked character, the apnoeic pause being shorter, in some cases being entirely absent. This difference in the apnoeic pause has led to the conclusion that it is dne to the excessive storage of O in the air cells, thus rendering inspiration unnecessary.

The fact that hydrogen produces apnoea, although the hydrogen drives out the O from the lungs, indicates that the O does not furnish a full explanation. Apnoea, although hydrogen resulting from inflation of the lungs with air represents a condition in which enough O is found in the lungs to supply the blood. The fact that if the vagi nerves along which impulses pass from the lungs to the center be cut, hydrogen filling the lungs causes violent ~~violent~~ dyspnœa, whereas inflation of the lungs with air produces no result at all, seems to suggest that the repeated respirations stimulate the pulmonary peripheries of the vagus nerves, producing impulses which in-

hibit the respiratory center by depressing it and so preventing the respiratory center from acting.

Apnea may result from inflation of the lungs with air, pure O or pure H, the pause representitg the only difference between these, being shortest when pure H and longest when pure O is used. If the vagi nerves be cut and the lungs be inflated with H, no apnoea results. During the deglutition process respiration is arrested but this takes place by the inhibition of the centers, the inhibition originating in the terminals of the glosso-pharyngeal fibres. Apnoea may therefore be caused by mechanical action or by gaseous stimulation. In the latter case the apnoea is due to the excessive amount of O stored up in the lung alveoli; in the former case it is due to inhibition of the respiratory center, the inhibition being aroused in the vagus nerves and resulting in the arrest of the repiratory impulses. Both of these causes may be combined in the production of apnoea. If the act is voluntary, the breath may be held for a considerable time, especially if the act of holding the breath is preceded by a number of deep respirations. In this case the probability is that the nervous impulses are sent down from the higher psychic centers inhibiting the action of the respiratory center.

The will, however, cannot destroy the respiratory impulses because the will or the psychic influences from the psychic center cannot restrain those impulses which proceed from the respiratory center without destroying the respiratory activity. When the will is checked for a time the power of the respiratory center, the inhibition is then withdrawn, the respiration becomes normal. This inhibition may take place, either voluntarily or involuntarily indicating that the will has very llttle controle of respiration. This is shown from the fact that a number of deep respirations must necessarily precede even this brief stoppage of respiration. It cannot at once take place, that is, the will cannot suspend respiration without certain physical conditions being fullfilled, preparatory to the exercise of the will. This is sometimes spoken of as a brief conscious apnoea.

A pathological apnoea we have already described in connection with the Cheyne-Stokes breathing. The movements of respiration in this form of breathing gradually diminish in rapidity and also in extent until the respiration ceases during the apnoeic pause. These respiration representing a series representing successive respirations, diminishing both in extent and in intensity. This apnoeic pause in the Cheyne-Stokes breathing is alternative by dyspnoeic respirations, this dyspnoea respiration constituting the series of breathings or respirations. This form of breathing is explained by some Physiologists as due to malnutrition of the respiratory center, the variations in the respiration representing the decadence of respiratory activity. Other Physiologists, however, believe that this form of breathing is due to the inhibitory impulses These inhibitory impulses arise from the higher centers or possibly are due to cardio-inhibitory action as this form of breathing is always associated with fatty degeneration of the heart. In *hyperpnoea* we find increased activity in the respiratory center. It is called thermopolypnoea. The increase of the respiratory activity is due to the direct stimulation of the respiratory center, either through a rise in the blood temperature or reflexly due to stimulation of some of the sensory fibers found in connection with the surface of the body, arising, for example, from an increase in the external temperature. When the body becomes abnormally heated by the presence, for example, of the body in a medium of hot air, the respiration becomes faster. This hyperpnoeic condition is peculiarly characteristic of heat dyspnoea, even when the blood becomes

hyperoxygenated. No apnoea results. This forms an additional proof of the fact that the apnoea is not produced by an excessive supply of O.

Dyspnoea is difficulty of breathing. It is generally found accompanied by slow and forced respirations. There are different forms, however, of dyspnoea. From some cause or other sufficient O does not enter into the blood or the blood becomes unduly venous on account of the excess of CO_2; hence, the respiratory center is strongly stimulated and violent inspirations, followed by violent expirations, take place. This dyspnoeic breathing is quicker and deeper, the venosity of the blood arousing the respiratory centers so that respiration becomes violent, resulting in the activity of all the muscles of respiration and almost all the muscles of the body.

There is a form oj dyspnoea due to the existance of certain substances in the blood, these substances being derived from the muscles during active muscular operation. Dyspnoea may result either from a deficiency of O or from an excess of CO_2 or we may find both of these conditions combining together in the production of dyspnoea. In the case of the confinement of an animal in a limited space where the O supply is limited or when the air in such a limited spacc is saturated with H, in this case dyspnoea results, even when the CO_2 in the blood is less than normal. It may result also from breathing an air containing a large quantity of CO_2, even although more than the regular quantity of O is present and even, although, the blood contains less than the normal quantity of CO_2. For example, if a person is forced to breath an air containing 10 per cent of CO_2, dyspnoea results although there is sufficient O present both in the blood and in the air. If an animal breathes pure N the result is, that the respirations become frequent and the inspirotions are very strong. In the case of an animal breathing an air laden with CO_2 the respirations become slower and they are marked by strong expirations. This marked increase in the depth of respirations is due, not only to direct action upon the respiratory center but also and especially to the reflex actions upon the center conveyed through the sensory fibers of the large bronchi. Hence, the depth of respiration in connection with the inhalation of excessive CO_2 arises from the stimulation of the sensory fibers of the bronchial mucuous membrane. In the case of the inhalation of air deficient in O the exhalation of CO_2 is not affected at all.

It is marked, however, by increased blood pressure. This increased blood pressure continues for a considerable time before death takes place; death being preceded in this case by certain disturbances in the motor activity such as we do not find in the case of death, resultihg from the inhalation of air excessively charged with CO_2. The difference then, between the inhalation of air excessively laden with CO_2 and air deficient in O is explained in connection with the blood. The blood that is deficient in O influences the inspiratory center, whereas the blood that contains an excess of CO_2 affects the expiratory center. During the contraction of the muscles certain substances are formed, which pass into the blood, and consequently affect the respiratory center. Accompanying this muscular activity there is an increase in the respiratory activity, and in the case of strong muscular action dyspnoea, more or less marked results. These products of muscular activity, pass into the blood and the blood then acts as a stimulant upon the respiratory center. These substances are not known, although propably they are of an acid nature and are broken up in the blood, being carried through the system in the circulation. If the blood that flows to the brain is higher in temperature than the normal temperature of the blood, for

example, if the blood of the caroted artery is heated artificially above the normal temperature, this will produce dyspnoea. In fact, anything that weakens the circulation, or diminishes the amount of haemoglobin found in the blood will cause dyspnoea,

If, for example the carotid and intervertebrate arteries are ligatured thus cutting off the blood supply to the medulla dyspnœa results, the blood in the medulla region being excessively charged with CO_2 and deficient in O. This accounts for the fact that people who are affected with heart trouble or suffering from anæmia become dyspnœic with the least over exertion. In the same way anything that tends to prevent the interchange of O and the excretion of CO_2 assists if it does not produce dyspnœa. Hence, pneu monic persons and those who are affected with lung tuberculosis are subject to dyspnœa on very slight exertion; Dyspnœa is characterized in general by an increase in the frequency and in the depth of the respiratory movements, hence, the ordinary muscles of respiration, the diaphragm and intercostals, especially tee external intercostals are assisted by the scaleni and by the serrati postici muscles. The ribs become elevated and depressed forcefully and the larnyx that normally is resting is forced up and forced down with considerable force; Hence, dyspnœa may be caused in the following ways: 1st of all, by a puncture opening into the pleural cavity thus obstructing the lung distension. 2d. By an excessive hemorrhage the blood loss in this case affecting the ordinary activity of the respiratory center. 3d. By diminishing the circulation of the blood, at least in the brain so that the brain does not receive a blood supply sufficient to keep the brain in active operation. This takes place, for example, if the valves of the heart are in a diseased condition or by an interference with the circulation of the blood in the carotid or in the juglar veins. 4th. Anything that prevents the normal passage of air to and from the lungs, as for example, in the case of partial strangulation. 5th. Congested conditions of the lungs. This condition lessens the respiratory surface, in that case preventing accumula tion of O and thus interfering with the respiratory actlvity.

Asphyxia.—This literally means without pulse, but Physiologically it is applied to that state ~~to that state~~ in which there is a cessation of the respiratory rhythm due to the exhaustion of the respiratory center. Asphyxia generally results from the interruption of the process sf respiration, caused by the deprivation of air; for example, by placing an animal in a limited space so as to lead to the increase of CO_2 in the blood, cutting off the supply of O. Asphyxia may take place suddenly, as, for example, in the case of the complete blocking of the trachea, or it may take place gradually, as in the case where you have only the partial blocking of the trachia and other cases. In any case, whether the asphyxia is sudden or gradual, it is divided into three stages. 1. During the first stage we find difficulty of breathing. The respirations in this case are rapid, irregular and very soon become deep and labored, representing a condition of hyerpnœa. Asphyxia, we will find, is a combination, hyperpnœa and abnormal conditions that we find in connection with respiration. The muscles of respiration, especially the muscles of inspiration, are subjected in this stage to very strong contraction, and those muscles in the chest and in the abdomen, ~~and~~ ~~those muscles~~ in the chest and abdomen which are connected with inspiration contract very powerfully at intervals. After a brief space this intermittent contraction passes to the muscles of the lower part of the body, chiefly the flexor muscles. Through out the first period of asphyxia the O is exhausted, the blood becomes venous and the respiratory centers are sub-

ject to stimulation by the velocity of the blood, chiefly the inspiratory part of the center giving respirations of increaesd frequency and death.

2d Stage. The violent convulsions give place to deep and slow expiratory movements, the dyspnoea giving place, as we have said, to the convulsions. The inspiratory center ceases to be affected to any great extent and inspiratory movements become weak, whereas, the expiratory part of the respiratory center is strongly moved, resulting in very strong intermittent expirations, the respirations becoming slow and also deep. This 2d. stage like the 1st stage continues for about one minute. During both of these periods the blood becomes deficient in O resulting in the blue discoloration of the skin and also the blue discoloration of the lips and gums. The blood has become more venous, resulting in a strong stimulation of the cardio-inhibitory center causing the heart's action in contraction to be sensibly diminished. The respiratory centers in the medulla are excited and in the latter part of this second stage at least the spinal cord is also strongly excited, the vaso-constrictor center causing contraction in the capillaries and also producing a rise in the pressure of the blood.

3d. Stage: During this period general exhaustion follows, resulting in collapse. The inspiratory muscles at first act weakly and only intermittently, while the expiratory muscles give occasional spasmodic contractions, resulting in convulsions. In the same way the muscles of the extremities become spasmodically convulsive in their movements, chiefly the extensor muscles; gasping being associated with sharp, short respirations.

The pupils of the eye then become dilated, the lids of the eye do not close when the eye balls are touched, consciousness disappears and the reflex actions cease. The muscles, particularly the muscles of respiration, become soft and the convulsions give place to a quiet comatose condition. Afterwards the body becomes arched backwards especially the head and the body trunk. The lower extremities become stiff and stretched, the nostrils being expanded and the heart paralyzed. The right auricle and the right ventricle are dilated on account of the free flow of venous blood; while the cardiac muscular tissue become enfeebled, loose and flaccid. Finally the heart ceases to beat, the pulse cannot be felt and the respiratory centers become completely paralyzed. This period normally lasts 4 or 5 minutes. The heart, however, continues to beat very feebly for some time after the respiratory actions have ceased. If artifical respiration is induced before the cessation of the heart beat, the respiratory movements may be restored and the other functions revived. If asphyxial death results from the obstruction of the trachea, the three periods are somewhat shortened, the whole asphyxia period lasting about 5 minutes. If asphyxia comes on gradually, then the death takes place very slowly and it may result without any disturbance of the motor activity.

In the case of death by drowning, the complete submersion of the body for a very few minutes results fatally, death resulting either from suspended respiration or from the failure of the heart's action, It is more difficult to revive persons who have been submerged in water then to revive those who have become weakened simply on account of the lack of O. It is said by the Physiologists that resuscitation is impossible after complete submersion for five minutes. Newly born children are able to sustain life longer in the case of submersion than adults. After death, on examining the body, the blood is found to be very dark, particularly in the lung capillaries. In some cases the venous blood is almost black, the auricle and the ventricle on the right side of the heart, and the lungs together with the veins being gorged with blood, whereas, the arteries are almost, if not entirely empty of blood. This is due to the

forcing of the blood into the venous circulation by the elasticity of the large arterial vessels.

During the 1st and 2d periods the pressure of the blood increases, the smaller vessels contracting, this contraction being due to the stimulation of the vaso-motor center in the medulla, increasing the strength of peripheral resistence. The heart's action becomes stronger for a short time, although the heart beats become less numerous under the influence of the cardio-inhibitory center, which has become excited. The heart beat at this point becomes more forcible. After this forcible beating of the heart for a short period, the heart action becomes feeble on account of the large quantity of the venous blood in the heart, the left ventricle being unable to force the blood out of the heart against the strong force of peripheral resistance. At this point the blood pressure falls to its lowest, marking the beginning of the 3d stage. This takes place on account of the paralysis of the vaso-motor center, due to the action of the venous blood. The venous blood, as we have said, gorges the right side of the heart when the blood flows from the small capillaries into the veins and then into the heart, injuring the cardiac muscle, and then enfeebling the action of the left ventricle, diminishing the peripheral resistance which results in a large fall in the arterial pressure and in the complete collapse of the system. These changes result mainly from the deficiency of O in the blood. With an increase in the velocity of the blood, the respiration becomes more frequent and greater in force, the expiratory action predominating over the inspiratory action, under the influence of the muscles that are brought into play, all the muscles of the body in this case being brought into active operation. These expiratory movements merge into the expiratory convulsions due to the excitation of the medullary center by the venous blood. If the spinal cord is divided below the medulla these convulsions do not appear. If the brain above the medulla is removed, these convulsion reactions still continue, indicating—what we will find later—that the respiratory center is in the medulla. This center is sometimes called the center of convulsion,or convulsive reactions. Although, the question of its independent existence is a matter of dispute. Some have indentified this convulsive center with the expiratory part of the respiratory center. If there is an independent convulsive center it must be in close relation with the main respiratory center because there is a close connection between the expiratory movements of respiration and the convulsive reaction. If the blood vessels supplying the brain are ligatured the same convulsions may be noticed, the centers of nervous activity in the medulla becoming asphyxiated through lack of blood containing the O. If there is a large loss of blood by hemorrhage, the same results may be noticed. These results are due to the stimulation arising from the deficiency of blood. During the last stage of the convulsions we find that these convulsions give place after the exhaustion of the nervous system to a calm and quiet condition, being interrupted at varying intervals by the inspiratory gasps. These inspiratory gasps mark the near approach of death. These inspiratory gasps also represent the gathering force of the inspiratory part of the respiratory center, until the center becomes entirely exhausted and all activity ceases in death.

SECTION X.—The Innervation of Respiration.

Pulmonary respiration we have said is carried on by means of the action of a number of muscles, some of which are in positions widely separated from each other, but all of which act together in a co-ordinate manner. If the intercostal muscles were to contract before the scaleni muscles, then the entrance of air and its elimination would be interfered with. Normal inspiratiom implies a quiet action of the various muscles and a forced respiration implies a

forced contraction of the muscles, otherwise the respiratory action would be impeded. All this co-ordination of action is accomplished by co-ordinating nerves. These movements are carried on involuntarily and autmoatically, the mechanism being so arranged as to possess self-controlling power. The muscles of respiration can be called into activity by the exercise of volition and the will can to a certain extent modify respiration. Yet the breathing is not normally voluntary. That this is proved by the continuance of normal breathing during unconsciousness and after the removal of the higher parts of the brain above the medulla in which the psychic centess are located. These muscular actions are all controlled by a nerve center situated in the posterior part of the floor of the fourth ventricle. If one phrenic nerve is divided the diaphragm upon that side ceases to move although respiration is not suspended. If the other phrenic is divided the whole diaphragm ceases to move and breathing in the thorax becomes very difficult. If one of the intercostal nerves is divided the intercostal muscles cease to act, corresponding with the nerve cut. If the spinal cord is cut below the origin of the roots of the phrenic nerves the respiration in the thorax ceases and the diaphragm still acts, the breathing being more rapid. If the cord, however, is divided just below the medulla all respiratory movement ceases in the thorax, the nasal portion and the glottis still continue to act. If the facial and the glosso-pharyngeal nerves be then divided these movements also cease Thus we have the proof of the co-ordination of action in the production of the respiratory movements, different parts of the nervous system under the direction of the center in the medulla co-ordinating the different parts of the respiratory mechanism. The complexity of the center is manifest for in ordinary inspiration we find a number of complex co-ordinating impulses followed by a number of complex co-ordinating impulses in expiration. Even when respiration becomes forced the co-ordination of the ordinary and forced respiration is complete. Even in dyspnoea and asphyxia the co-ordination is not lost until the whole body is thrown into convulsions. This does not take place however wholly in the centers for the co-ordination is completed in the passage from the centers along the efferent path through nerve cells and nerve fibers, the nerve cells playing a part that is analogous to the main center, co-ordinating the impulses that are to be sent out along the motor nerves. This is evident from the fact that in young animals after the medulla is removed respiration may be kept up artificially. This indicates that the entire nerve cell mechanism of the spinal cord plays an important part in the co ordination of the impulses. In addition to this great center, other centers of lesser importance have been spoken of in connection with the spinal cord, these being called subordinate centers. In connection with the respiratory center there are also certain nerves that bear the impulses to and away from the centers.

INNERVATION OF RESPIRATION.

1. The respiratory centers (see the brain) except the medulla, may be removed and yet the respiratory movements will continue normally. If, however, the lower part of the brain is destroyed the rhythm cases. Respiration continues normally after the section of the spinal cord below the beginning of the phrenic nerve Flourens by such experiments as these has concluded that the center of respiration is in the medulla, at the lower extremity of what is called the V in the medulla the calamus scriptorius in the gray matter on the floor of the 4th ventricle. He found that by destroying that part, respiration was entirely arrested and death resulted in a very short time. On account of this he located the respiratory center in a region, 5 mm. in diameter between

the nuclei of the vagus nerves and the spinal accessory nerves. The destruction of this portion of the brain was found to result fatally, and hence, it was called by Flourens a vital knot, noeud vital. Later researches have somewhat modified this conclusion of Flourens. It has been found, for example, that the area of the Flourens vital knot consists not of a center but rather of groups of nerve fibers arising from the roots of the vagi, the spinal accessory, the trigeminal and the glosso-pharyngeal nerves, these forming nerve p aths rather than a center. It has been shown by some recent Physiologists that the removal of this vital knot does not of necessity prove fatal and later it has been found that respiration is not suspended, either by the section of the spinal cord below the medulla or by the division of the medulla just below the calamus scriptorius. The stimulation of the vital knot does not excite the respiratory activity but simply influences the characteristic tonicity of the diaphragm. Without locating or attempting to l ocate exactly the center of respiration, most recent Physiologists have concluded that there is a center of respiration, some were in the lower part of the medulla. This center consists of two parts, one part on each side of the median line, the two parts being closely connected together by means of commissures. These two parts of the respiratory center act simultaneously and yet their action is independent, having connections with the lungs and with the respiratory muscles on the two sides. If the median line is divided the two parts will continue to act simultaneously, whereas if the part on the one side of the median line is destroyed, suspension follows in the case of respiration on that side of the median line. If, on the other hand, after the division of the median line, one of the vagi is also divided, no impulses reach the center on that side from the lungs, producing the slowing of the action of the muscles of respiration and increasing the strength of the inspirations. If, on the other hand, the median line is left intact, stimulation of one of the vagi affects both sides and stimulation of the central end of one of the cut vagi tends to increase the activity of both sides. If the vagi are divided and the stimulation is applied to one of the vagi, high up in the neck, the respirations may cease altogether on that side if the stimulation is strong. From this it is concluded that the two parts on either side of the median line connected with the respiratory center act together as a single center while each part has the power of acting independently. Each central part is supposed to consist of two parts, the one on inspiratory center controling the inspiratory muscles, and the other an expiratory center controling the expiratory muscles. If stimulation is brought to bear on the inspiratory center the inspiratory muscles contract and if the excitation is strong enough the inspi rations are spasmodically arrested. Marckwold by the use of electric stimulation in the case of the medulla proved that the expiration or the inspiration depended upon the intensity of the stimulation, the period of the respiratory circle during which the stimulation was applied and the position in which he placed the electrodes. The motions were produced by excitation of the different or the sensory fibers indicating that they were reflex in their action so that by electrical stimulation a purely artifical respiration can be prodnced. Under this electrical stimulation he found that the expiratory center was more difficult to call into activity than the inspiratory center. This connection is of such a nature as to give to the center of inspiration an accelerator action and to the expiratory center an inhibitory action. In the case of the stimulation of both inspiratory and expiratory centers the accelerator action overbears the inhibitory action, giving to the whole respiratory center a prevailing accelerator activity ~~because the accelerator activity~~ because the accelerator element seems to be more powerful and more easily excited.

Rosenthal has proved that if the medulla is cut off from all afferent connection by cutting it below the corpora quadrigemina and also by ~~driving~~ the posterior roots of the spinal nerves and the pneumogastric, respiratory activity still continues. These respiratory actions however take the form of spasms, indicating that the respiratory center in the medulla can produce automatically spasmodic activity. The efferent impulses, therefore influence reflexly the normal respiration.

Some writers claim that there is a respiratory center, or centers in the spinal cord acting automatically and also by reflex action from the peripheral. Other Physiologists have claimed that higher centers exist in the upper part of the brain. One has been located, for example, in the prominence of the grey matter of the brain between the optic tracts and the corpora albicantia, the tuber cinereum associated with violent respirations upon stimulation. This has been called a polypnoeic center. Upon the stimulation of this center respiration becomes very rapid. If a rabbit, for example, is placed in a high external atmosphere, respiration becomes very quick. If this part of the brain the tuber cinerium is extirpated these increased respiration are either arrested altogether, or the respirations become much slower. Another center has been located by some Physiologists in two anterior bodies of the corpora quadrigemina, associated with expiration and inhibitory action. An inspiratory center is also claimed in the posterior bodies of the corpora quadrigemina. This portion acting as an inspiratory and accelerator center. Another center is located in the upper part of the pon s Varolii, acting as an inspiratory accelerator center. Other physiologists claim that in the lateral wall of the 3d ventricle there, is a center which deepens inspiration by stimulation and on the floor of the 3d ventricle there is said to be; an area connected with the optic and the auditory nerves, under stimulation accelerating the respiratory rate, and if excited by strong stimulation, particularly mechanical stimulation, arresting the inspiration altogether. There can be, however, no satisfactory reason to establish any of these as true centers. Even if these are centers it is possible that they are entirely subordinate to the main center in the medulla, these stimulations passing downward to the true center.

In order to establish any of these as independent centers it would have to be proved that the injury or removal of these centers would result in stopping or modifying respiration and also that there are nerves connected with the respiratory organs and muscles leading to these centers. Some have regarded the spinal centers as the principle centers. This however is impossible. Respiratory centers have been supposed to be located in the spinal cord chiefly for the reason that after dividing the spinal cord from the brain, where it joins the medulla, respiratory movements continue at least for some time. In the case of new born animals respiration will continue some time under these circumstances. If animals have been artificially subjected to respiration and after cessation of artificial respiration the spinal cord is cut below the medulla respiration continues. From this it has been concluded that a respiratory center must exist in the cord acting both automatically and reflexly. There is probably a chief center in the medulla and subordinary centers in the cord, in special cases these centers acting alone when the great center is inactive from some cause. But the respirations in such cases are irregular and rather spasms than respirations of a normal character. It has been observed that if the medulla be removed from the influence of all afferent nerves by cutting it under the corpora quadrigemina and also dividing the vagi and the posterior roots of the spinal nerves, respiration continues but the respirations assume a spasmodic form of inspirations and expirations. Thus by automatic activity the medulla

can produce spasmodic actions. Normally, however, it is subject to afferent impressions so that normal respiration depends upon reflex action. The rythmic action of the center of respiration is communicated by means of impulses to the respiratory movements, the center discharging those impulses. This power of producing the rythm is inherent in the center, if not entirely, to a large extent, not being caused by external stimulation so that the center is automatic to external stimuli. It is not so in relation to the blood, for when the center is in isolation from afferent impulses, the activity is continued on account of the stimulation of the blood, the automatic discharge of impulses depending upon the blood.

The rythm must be inherent in the center, for it is not destroyed by dividing the vagi and the glossopharyngeal, and the spinal cord either below the medulla or in the lower cervical area. The activity of the center and its rythm may be modified by influences reaching it from the higher centers ; for example the effects of the various mental states and emotions upon respiratory movements is well known. It may also be influenced by the will for the respiratory rhythm may be voluntarily altered both in character and rate. The respiratory center is thus not a voluntary center, although it may be influenced by the activity of the higher, voluntary centers. As the action of the respiratory center still continues when the afferent nerves leading to it are divided, the center cannot properly be a reflex one. It must, therefore, be an automatic center. Yet though the activity of the center does not depend upon reflex stimulation, its action may be and continually is influenced by impressions reaching it along afferent nerve paths. If one vagus nerve is cut the respiratory movements become slower ; if both are cut respiration becomes slower and deeper, the pause in each respiration being ~~marked by~~ prolonged. The stimulation of the cut end of the central portion of the vagus nerve lower than the laryngeal branches restores the normal rapidity and character of the respiratory rhythm, and if the stimulus is sufficiently strong causes the diaphragm and other muscles of inspiration to pass into a state of tetanus so that respiration is suspended in a state of deep respiration. From this fact, that section of the vagi diminishes respiration and that stimulation of the cut end causes an increase, it is evident that under ordinary circumstances influences are continuously ascending the vagi to the center from the lungs and quickening the action of this automatic respiratory center. By the stimulation of the sensory nerves of the skin heat tends to increase, and cold to inhibit the respiratory activity.

The rhythm of respiration includes the rhythm of both inspiration and of expiration. Normally, in inspiration we find muscular action, whereas in expiration, as we said before, there is very little of the muscular element that enters except in the case of forced or labored expiration. In the labored expiration the muscular element is really the prevailing element. Thus, there is an alternation between inspiration and expiration more marked when either inspiration or expiration becomes deep. Some Physiologists think that in the nerves there are to be found fibers connected both with inspiration ~~and~~ expiration, thus controling the inspiratory and the expiratory centers and alternating in the carrying of impulses to the centers. Inspiration and expiration takes place alternately, however, without such a connection on the part of the vagus nerves. This is evident from the fact that by the section of the vagus and the consequent separation of the center or centers from the action of the vagus nerves, alternation of these respiratory movements still continues. The rhythm of the inspiratory movements is dependent, therefore, upon the respiratory center aside from its connection with the afferent nerves. The activity of the

respiratory center is manifested in certain chemical changes that take place in the nerve cells contituting the center and this activity of the nerve cells is sustained by its relation to the blood flow and the rate as well as the character of the respiratory movements, depending upon, not a single influence but a complexity of influences which may and do continuously affect the center; for example, the will and the emotions and the condition of the blood supply, particularly the blood supply to the brain. If both the vagus nerves are divided we find that respiration continues but only in a modified form. If the spinal cord is cut below the medulla the respiratory movements still continue, at least in the face and in the larynx, indicating that the activity of the respiratory center continues, even, although the vagus influences are entirely cut off and even when the movements of the thorax cannot be normally executed. The cranial nerves, except the vagus, are not especially brought, therefore into play in respiration, aside from the fact that they constitute a path for the conveyance of nerve impulses. If these cranial nerves are cut, leaving the cord undivided, the respirations still continue almost normally. This indicates that respiration discharges from the center do not depend solely upon the afferent impulses that reach the center along the afferent paths. Some of the impulses therefore originate in the center itself and the center, therefore, possesses the power of originating impulses, although these impulses are considerably modified by the afferent impulses. This indicates that the center of respiration is automatic in its action. Respiration is a double action so that nerve impulses may afiect either part of the center or both parts of the center. In this way affecting either part of the respiratory movement or both parts of the respiratory movements. Nerve impulses may diminish or increase the depth of the volume of respiration. They may also increase or diminish, the respiration rhythm, and this seems to be their sole function. Thus, the respiratory center is subject to the following influences:

1st. The influences of the higher centers. 2d. The influence of the afferent nerves, and 3d. The influences of the blood.

1ST. THE INFLUENCES OF THE HIGHER CENTERS.

All Physiologists admit that there is an influence exerted upon the respiratory center by the higher centers. For example, the strong excitation of any of the nerves of the special senses influence respiration. The optic and the auditory nerves on stimulation results in inspiration impulses and the stimulation of the olfactory nerves in expiration impulses. Similarly, the powerful excitation of the sensory fibers of the 5th cranial nerves as in the case of sneezing, results in expiratory movements. All the sensory nerves of the head act in a similar way conveying impulses to the brain producing inspiratory and expiratory impulses which are sent down to the respiratory center in the medulla. If the medulla is divided high up on the floor of the 4th ventricle so as to divide it from the brain respiration will cease for a few minutes and then may resume again, the breathing going on almost normally as before, the only difference being in the extent of the movement of inspiration, the variation being almost the same as we find in the case of sleep. If a transverse division is made lower down the respiration become forced, and if the incision takes place at the point of the calamus scriptorius, the respirations become periodic with long pauses, the respirations gradually diminishing in force and in number. In this condition by the stimulation of the sensory cutaneous nerves this periodicity will be removed and the normal respiration will be restored. The simple pressure upon the medulla cannot produce this periodicity of respiration.

There must be an inhibition of some of the normal stimuli that come down to the respiratory center in order to interfere with periodicity.

This throws some light upon the abnormal condition of respiration that we find in certain diseased conditions of the heart and of the lungs in which, as we said before, breathing becomes perodic with long pauses, lasting about 8-10 of a minute succeeded by superficial respirations which become deeper and deeper until the series of 20 or 30 respirations, is completed, after which a new series begins of the same character, each series becoming deeper in the first part, and lighter in the second part, as the series goes on. In this case the pause may be shortened by arousing the interest of the patient, in other words, by exciting the higher centers, and also by the section of the vagi. In the last case section of the vagi causes these periodic breathings to give place to spasmodic breathing, hence, perodic respirations arise when the higher nervous centers are in a condition of lethargy, either inactive on account of inability to perform their function, or failing on account of inhibition of some kind to send down impressions from the higher part of the brain to the lower centers along which we find the respiratory center. Thus the Cheyne-Stokes breathing occurs when higher centers send down no impulses to the respiratory center. This indicates an important point in connection with the innervation of respiration, namely, that the normal condition of the respiratory centers depends upon two things. 1st of all, upon the active normal condition of the higher centers of the brain, and 2d, upon the activity and operation of the vagus nerves through which the afferent impulses are brought to the respiratory center.

2D. THE INFLUENCE OF THE AFFERENT NERVES.

These afferent nerves are the vagi, the glosso-pharyngeal, the trigeminal and the cutaneous nerves. Impulses passing along the pneumogastric have an important influence on the respiratory center because this, as we said, bears the afferent impulses to the respiratory center. Hence the action of the vagi is the most important in connection with respiration. These influences of the vagi nerves can best be brought out in connection with the section of these nerves and the effects that are produced by stimulation of various kinds applied to these nerves when divided. When the medulla has been separated from the higher centers, if the vagi are divided there results a lengthened spasm of inspiration followed by spasmodic inspiration and expiration, resulting in a short time in death.

If the vagi, on the other hand, are cut off before the separation of the medulla from the higher centers the respiration will continue for a time normally and after a few moments the respiration will become deeper and slower followed in a few moments more by respiratory spasms. The absence of impulses passing through the vagi can be made up for by certain impulses arising in the brain and passing from the higher portion of the brain to the respiratory center. If the impulses are suspended only from the one side the rhythm is not affected, but if the impulses from both sides are suspended the centers act without any rhythm at all. This indicates that the rhythm of respiration depends upon the afferent impulses that are borne to the respiratory center by the vagi nerves. The vagi and the upper parts of the brain are therefore the media through which pass the impulses that influence the respiratory rhythm and the respiratory action. In the case of the vagi these impulses are constant; whereas, in the case of the upper parts of the brain the impulses are only occasional and intermittent. It is through this latter channel that the volitional and the emotional and the mental impulses pass to the

respiratory center as well as those impulses that come from the special organs of sense. The lungs send their impulses along the vagi, these impulses affecting the center in causing the discharge of energy. The excitation of the vagus nerve in the neck produces strong inspirations and if this excitation becomes strong the inspiratory muscles may be thrown into a tetanic condition. In some cases the strong stimulation of the vagus nerves produces expiratory activity acoording to the period of the respiratory rhythm at which the stimulation is applied. Hence we conclude that the vagus contains both the inspiratory and the expiratory fibers. The impulses borne along the vagus so stimulating the respiratory center that there is rhythmic liberation of energy taking place which results in inspiratory and expiratory movements.

Marckwald says the respiratory center is automatically active but if the vagus influence is cut off then only spasmodic action results in the case of respiratory activity. The vagus is thus in constant operation conveying those impressions from the lungs to the center producing this discharge of energy which prevent s the centers from becoming over-stocked. The center in the medulla is th us influenced from below by the vagi nerves and from above by the upper centers. The division of one vagus may have no affect at all or it may have only a slight effect upon respiration. The respiratory activity diminished gradually, thus resulting in the production of slower respiratory movements and also in longer and deeper inspirations and shorter expirations. The effects quickly pass away. If both the vagi, however, are divided, the respiratory rhythm is diminished sometimes at once and at other times later.

This is followed by slow and deep inspirations. The inspirations then become gradually more forcible, accompanied by strong expirations, and a pause between each inspiration and expiration representing the abnormal pause. If the divided ends of the vagi are left unstimulated, the respirations become irregular, the inspirations becoming weak, the expirations are intermittent and between the inspirations and the expirations there are long pauses. These varying results in connection with the division of the vagi nerves are explained by the fact that the inspiratory fiibers are less sensitive to weak stimulation than the expiratory fibers, and that there is mechanical stimulation when the fibers are divided. This mechanical stimulation arouses the expiratory activity. If the central ends of the divided nerves are irritated the inspiratory and the expiratory impulses become more powerful. If the one vagus nerve be divided and the central end of the cut nerve be stimulated. different results will follow these results depending upon the character of the stimulation and also the strength of the stimuiation. For example, electric stimulation affects both inspiration and expiration. Mechanical stimulation affects only inspiration. Chemical stimulation affects only the expiration. If the electric current is weak, inspiration is lessened and expiration is lengthened. If the electric current is increased in strength the expirations become more frequent and the inspirations become deeper and stronger, the stronger current arousing the inspiratory fibers and accelerating the inspirations. If the vagus nerves become exhausted by excessive stimulation, then the application of the stimulation to the central end of the cut nerve results in increased expiration, the inspirations, on the other hand, being very short and weak, where as the expirations are long and deep, a pause occurring between the two. If the irritation is made very strong then the respiration is arrested in expiration. These opposite results are due to the two kinds of fibers, the two kinds of fibers being different in function, the one accelleratory and the otner inhibitory. Each fiber has its own function, the one bearing impulses affecting the expiratory part and the other impulses which affect the inspiratory part of the center.

The different fibers are differently affected under the different degrees of stimulation. Both kinds of fibers carry impressions originating in the vagi peripheries in the lungs. The inspiratory fibers respond more readily to weak stimulation, and they are not so easily exhausted. If the stimulation, on the other hand, is medium or strong, the inspiratory fibers are more easily affected so that the inspiration action prevails. The expiratory impulses, however, may arise in the laryngeal nerves, especially in the superior laryngeal.

The superior laryngeal nerves are sensory branches of the vagi passing to the larynx. The excitation of these produces expirations and as the nerve fibers are very sensitive strong stimulation produces a stoppage of the respiration with a tetanic condition of the muscles of expiration. For example, the presence of irritant substances in the larynx immediately stops inspiration. When the stimulation is weak respiration becomes slow and the pause is lengthened. If the stimulation is strong the arrest of respiration takes place in expiration. These nerves seem to be expiratory nerves acting as such, even when the medulla is divided from the upper part of the brain. They do not act constantly like the vagi but simply act temporarily when some irritation affects the larynx, impulses being originated that stop inspiration. The impulses which arise in the lungs originate from the mechanical stimulation of the lungs. Some Physiologists think that the stimulation arises from the gases that are contained in the air vesicles. According to this, during expiration the increased CO_2 contained in the vesicles stimulates the inspiratory fibers, terminating in the lungs, the impulses being carried to the inspiratory center. On the other hand, the dilatation of the lungs during the act of inspiration stimulated the expiratory fibers terminating in the lungs arousing impulses carried to the expiratory center. The mechanical lung movements, however, are stronger and originate the impulses which affect both inspiration and expiration. In the case of the glosso-pharyngeal nerves their division does not affect respiratory movements whether the vagi are divided or not. Their stimulation is followed by an arrest of respiration for a period equal to three preceeding respirations. After that breathing commences with inspiration just from the point where the diaphragm was arrested. The glosso-pharyngeal nerve, therefore, is a nerve of inhibition coming into active operation at the commencement of deglutition. During the process of deglutition respiration is stopped, there is first a stimulation and afterwards an inhibition the stimulation taking place through the sensory nerves of the tongue and the pharynx and the inhibition through the glosso-pharyngeal nerves. The inhibition of respiration makes it possible to swallow either food or drink without drawing them into the larynx. The stimulation that passes through the sensory nerves to the center excite the mylo-hyoid muscles used in swallowing and then the inhibition takes place so arresting the breathing as to prevent the food from passing into the lungs. Thus, during the deglutition process the breathing is temporarily arrested. Nervous impulses seem to pass by irradiation from the deglutition center to the respiratory center, causing a short inspiration followed by inhibition through the glosso-pharyngeal during a longer period. As soon as the food is swallowed the inhibition ceases and respiration is restored. The trigeminal nerves of the nose may be excited so as to cause the arrest of respiration in the case of certain irritants, for example, certain poisons, gases, fumes, etc.

Tobacco smoke introduced into the nostrils or into the lungs of a rabbit causes the stoppage of the respiration. In the same way ammonia breathed through the nose or introduced into the lungs results in tne arrest

of breathing in expiration. Odors may in the same way affect respiration through the olfactory nerves. Respiration is also influenced through the center by impulses conveyed along the cutaneous nerves. Slight stimulation of a sensory nerve has not any decided effect but if the exitation is strong there is first an increase in respiratory movements followed by a number of deep inspirations and the cessation of expiration, for example, the sprinkling of the body or the face with cold water, plunging into a cold bath excite inspirations by stimulating the sensory cutaneous nerves. These are reflex impulses and they are more decidedly marked if the higher centers have been severed from the medulla, becoming distinctly spasms, passing into the convulsions if the stimulation is very strong. If the splanchnics are stimulated strong expirations result and may result in an arrest in expiration. These actions, however, are only temporary and affect respiration occasionally.

3d. THE INFLUENCE OF THE BLOOD.

The respiratory center is also affected by the condition of the blood through the influence which the blood exerts on the peripheral extremities of the vagus nerves distributed to the lungs. The activity of the center is directly affected by the state of the blood. Various theories have been propounded historically as to the nature and the cause of this influence. It was first suggested by all that excess of CO_2 in the venous blood brought to the lungs stimulated the pulmonary branches of the vagi producing inspiration.

Later it was supposed that the same cause of stimulation applied to the sensory nerves. Rosenthal then suggested that inspiration resulted from the deficiency of O in the medulla, his idea being that the respiratory center depended for its stimulation to activity, upon the oxygenated blood, passing through it. The vagi impulses went up according to this view to the center, lessening the pressure existing in the center, the superior laryngeals increasing the pressure and thus respectively assisting inspiration and expiration. These theories have all been based on the idea that the stimulating cause of respiratory movements is found in the gases of the blood in its circulation through the brain, both deficient oxygenation and excessive carbonization exciting the center. The former produces inspirations and the latter expirations. In opposition to this theory we find Hering defending the idea that the mechanical expansion of the lungs during inspiration, arouses the vagi nerves which convey impulses to the center, giving rise to expiration. On the other hand, the reaction of the lungs resulting in contraction, stimulates other nerves, arousing the center to inspiratory action. This theory is negatived by the fact that respiration may continue after the removal of the lungs. The theory of Rosenthal based upon the deficiency of O as the cause of inspiration, is disproved by the fact that the blood of apnoeic animals is deficient in O. The most reasonable theory, therefore, is that defended by Marckwald, who says that the normal stimulation of the center of respiration is not due to deficient oxygenation of the blood or its excessive carbonization, as certain animals, such as the hybernating marmot have been deprived of the circulation altogether without interfering in any way with respiration. Respiration continues after a severe hemorrhage, the center continuing active, depending for its nourishment upon the fluid found in the substance itself, or lying between the different centers. When the anabolic process advances to a certain point the substance itself yields to dissolution during the anabolic process, thereby setting free eneygy that produces

spasmodic respiration. After this, a still further process of anabolism follows, resulting in the same change and so on successively.

During katabolism the branches of the vagi terminating in the lungs are active, producing by impulses sent to the center a discharge which maintains the respiratory rhythm and prevents spasmodic activity. If the anabolic process is stopped apnœa results, so that the vagi are the direct producers of the katabolic changes which result in respiratory action and rhythm. If the blood is more highly arterialized than it is normally from any cause, for example, by breathing an atmosphere too rich in O, the respirations are slowed and may even be suspended, the person passes rapidly into an apnœcic state. If, on the other hand, the blood is more venous in character than normal, for example, from the air not being allowed to enter the lungs, from breathing an atmosphere containing to much CO_2 or from such excessive tissue respiration as occurs in great muscular exertion, the respiratory movements become more rapid and also more violent. In addition to this, various other muscular movements, such as convulsions will occur, due to stimuli being sent from the respiratory center to various other motor centers. This state of dyspnœa continues until the energy of the respiratory center is exhausted unless fresh O is introduced into the blood. After this exhaustion the respiratory movements gradually cease and a state of asphyxia follows. From this it is evident that the increase of O with the diminution of CO_2 in the blood lessens while the opposite condition increases the activity of the respiratory center. A rise or fall in the temperature of the blood produces similar changes in respiration. Each successive breath is not determined by the blood condition in the brain at the time of breathing. The center of respiration is automatic, at least to external stimulation. The rhythm of respiration depends upon certain molecular changes taking place during the metabolism of the substance. Any impulses that affect the center have an influence upon this metabolism. The lack of O and the excess of CO_2 affect in some way the complex processes of katabolism and anabolism. In the case of difficient oxygenation rendering the structure of the center more unstable and in the case of excessive carbonization increasing its explosive character.

The same is true of excessive muscular activity sending up to the medulla a blood so changed in character as to affect the center, the blood leaving the muscles in case of great muscular activity, being more venous than normally. This venosity of the blood does not account for the change in the center, for the blood that leaves the left side of the heart in cases of great muscular activity is not less oxygenated, but more oxygenated than usual. This has led to the suggestion that it is due to the presence in the blood of an acid, like sarcolactic acid. Whatever the substance may be the respiratory center is affected through the blood. Thus, the respiratory center may be influenced by impressions sent along the afferent nerves by some disturbance in the gaseous interchange in the lungs or by so changing the character of the blood that circulates through the brain as to modify its metabolism. All of these influences affect the breathing and assist in the adaption of the respiratory mechanism to the bodily organism. Deficiency in respiratory aeration may be found in deficiency of O or excess of $C\ O_2$. If an animal breathes an air containing N, $C\ O_2$ is eliminated normally, and the blood has its normal amount of $C\ O_2$, yet the animal becomes dyspnoeic and asphyxiated, if the N is breathed for a time. This is due to the want of O. If the animal breathes an air laden with $C\ O_2$ with a sufficient amount of O present no asphyxia follows, although the blood is ex-

cessively laden with $C O_2$, the respirations become deeper and more rapid, inducing unconsciousness, indicating that excess of $C O_2$ affects the higher part of the brain. Thus the center of respiration receives it impulses from several sources. 1st, the higher parts of the brain. If these upper parts of the brain are inactive while the pneumogastrics are not divided, and in activity we have the abnormal respiration called Cheyne-Stokes breathing. 2d, the pneumogastrics are the constant bearers of impulses in connection with normal respiration in contrast with the upper parts of the brain which do not constantly influence ·respiration. These two represent the great nervous influences in connection with respiratory actions. 3d. The reflex activity of the sensory and cutaneous nerves may arouse respiratory action, although these cannot take the place of the constant action of the pneumogastric and the higher parts of the brain. 4th. Occasionally the influence of the 5th cranial nerve, the superior laryngeal and the glosso-pharyngeal nerves exert an inhibitory influence in slowing respiration and sometimes arresting it in expiration.

4TH. EFFERENT INFLUENCES FROM THE CENTERS.

From the center there are transmitted at regular intervals through the various nerve fibers nervous impulses which stimulate the different muscles of respiration. These impulses are all sent, or supposed to be sent through subsidiary centers situated in the spinal cord, before they actually reach the particvlar nerves which supply the respiratory muscles; and tnese subsidiary centers, may in exceptional cases, carry on the stimulation of the inspiratory muscles when the chief center, for some reason, has been disabled.

During respiration, the only efferent nerves along which the nervous impulses that produce contraction of the muscles pass are the phrenic nerves to the diaphragm, the intercostal nerves to the intercostal muscles and the facial nerves to the dilatores nasi. The division of one phrenic nerve results in the paralysis of that side of the diaphragm. The division of both phrenic nerves results in the paralysis of the entire diaphragm. In this case inspiration is hindered because it depends entirely upon the other muscles while the diaphragm is so relaxed as to be pulled inside the chest at each inspiration. In this way the diaphragm retards rather than assists as it normally does the respiratory activity, death results in a very short period from asphyxia. If the spinal cord is divided beneath the junction of the 5th cervical nerve the costal respiratory movements are suspended entirely. In this case the phrenic nerves remain intact, and hence, diaphragmatic action would continue almost uninterrupted. If a division is made of the spinal cord just above the origin of the phrenic nerves, both the costal and the diaphragmatic impulses are arrested although the respiration still goes on almost normally in the larynx. During normal respiration impulses are carried to the larynx, causing the glottis to open during inspiration.

These impulses pass along the laryngeal branches of the pneumogastrics. If the pneumogastrics are divided above the origin of these laryngeal nerves, respiration will cease in the larynx, the laryngeal muscles being paralized and the glottis being closed. The nerves of the lungs are the vagi, the sympathethetics and the upper dorsal nerves. The pneumogastric sends out branches into the lungs, these branches affecting the respiratory activity. Not only do we find general impulses passing through the vagi but there are special fibers fn connection with respiration. It has been

found, for example, that by excitation of one pneumogastric the bronchi of the lungs become constricted. On the section of one pneumogastric the bronchi on that side are dilated. The stimulation of the peripheral and also of the central ends of the divided nerves produces a contraction of the bronchi on both sides. The contraction, however, is less marked when the central end is stimulated. In the case of the administration of ether or chloral, this stimulation of the cut peripheral or central end of the vagus produces dilatation of the bronchi. This seems to indicate, first of all, the existence of constrictor and dilator bronchi fibers in connection with the pneumogastric. 2d. That both of these fibers, constrictor and dilator fibers, pass through the pneumogastric representing the afferent constrictor and dilator fibers, these being found by the stimulation of the peripheral end of the pneumogastric affecting both lungs so that each pneumogastric sends both constrictors and dilators to both lungs. When sensory nerves are stimulated, there is in fact only a slight effect by way of contraction. Various experiments have shown the existence of pressor fibers, the excitation of which produces a contraction of the air vessels of the lungs. The afferent pressor fibers are found in the vagi while the efferent pressor fibers pass through the sympathetics to the lungs. 4th. There are trophic fibers in connection with the vagus and also with the sympathetics. By dividing one vagus for example, there are found to be certain changes taking place in the lungs. For example, the inflamation that is present in the lungs due to the severence of the trophic fibers is accounted for by the fact that nutrition is cut off from the lung substance. 5th. There are also sensory fibers in the vagus reaching the trachea, the larynx and the lungs. This is proved by the fact that a section of these fibers destroys sensibility. 6th. In addition to these the sympathetic nerves furnish vasomotor fibers, these vasomotor fibers arising from the spinal cord in the anterior roots of the 2d, 3d, 4th, 5th and 6tn dorsal nerves, passing to the sympathetic and from the sympathetics to the first thoracic ganglion and thence to the lungs. These represent the chief nerves that we call the efferent fibers that reach the lungs.

THE RESPIRATORY CENTER IN THE FŒTAL LIFE.

In the fœetal life the fœtus receives O from and gives CO_2 out into the maternal blood. The respiratory center is in a condition of apnœa resulting from the large quantity of O in the blood and also from the absence of irritability. In the fœtal blood there is a large percentage of hæmoglobin and also a large capacity for respiration. Normally,however the child does not breathe in the uterus. In abnormal conditions, however, where the O supply is interfered with there may be respiratory movements even when the child remains intact in the fœtal sac. If the blood should become very venous this excitement would produce respiratory action. This respiratory action, however, would be abnormal. So long, therefore, as a child remains within the embryonic membrane, respiration normally is impossible even if the activity of the center of respiration is aroused, because if such respiratory movements look place then the nasal cavity would be filled with fluid. This fluid acts as an irritant upon different nerves, setting up impulses which inhibit the center of respiration so that in the fœtal life the respiratory system is intact and complete but there is a constant inhibition by the action of the fibers of the nasal cavity. This forms the reason why sometimes after birth, it is necessary to remove the mucous from the nasal cavity in order to produce respiration. The mucous so long as it remains in

the nasal cavity produces the inhibition of the respiration activity. The fœtal lungs have no air although they occupy the entire space of the chest cavity along with the other organs. When inspiration commences in a newborn child a very small amount of air passes in at the beginning of inspiration on account of the fact that the air cell walls are closely adhesive. The expansion of the lungs end air cells and the respiratory passages take place gradually. This accounts for the fact that respiration at first in the newborn child is not double but single, that is, consists of only inspirations until expansion of the lungs, air cells and air passages takes place when we find the normal respirations consisting of inspiration and expiration.

CHAPTER V.—ALIMENTATION.

SECTION I.—Introduction.

Alimentation includes those processes through which matter taken into the body becomes assimilated to the tissues and the fluids of the body and the waste matter afterwards is excreted from the body. The different solid and fluid substances necessary for the body nutrition constitute what we call food. The object of taking food, therefore, is to secure the nutrition of the body tissues. This food matter including the O taken in during inspiration passes through certain chemical changes, these chemical changes acting as a source of energy and in time of waste is excreted from the body in various forms. This food matter, therefore, provides for the energy of the body. Alimentation, therfore, supplies the matter for the tissues and also the energy for the body as a whole. In the interchanges between the matter introduced into the system and the system itself, energy is evolved by means of which the bodily function is performed. Thus, alimentation is aprocess consisting of a great number of stages all these stages representing certain actions that are necessary in the maintenance of the tissues and also in the maintenance of the bodily organs and the body as a whole. This process of alimentation must be understood because from the Osteopathic standpoint the lack of nutrition or the failure to perform the nutritive functions forms one of the main causes of the abnormal and the diseased conditions of the body. In fact it forms the main cause of diseased conditions because these alimentary processes are at the basis of the formation of the blood. The tissues of the body receive their nutriment and their O from the fluid which circulates through the whole system whose formation and changes through which it passes, represent the different processes of nutrition. Each of these nutrient processes may be said to include subsidiary processes but they are all united together, in the discharge of one main function, this function being the formation of the blood, its circulation and the process of blood purification.

The living tissues of the body in the performance of their functions pass through certain physical and chemical changes which result in the operations taking place in connection with metabolism of the human body. Alimentation represents a number of processes, each process representing some action having in view the normal maintenance of tissue and body function. This represents an interesting study from the standpoint of disease because where disease exists the nutrition process is at fault. The physical signs of weakness and emaciation indicate the failure of nutrition to perform its proper work. In some cases the fault may be in the food, for the food must be of the nutritive kind in order to be assimilated to the body substance. In other cases the fault lies in the processes through which the food passes, possibly in the blood formation or in the mechanisms of diges-

tion or circulation. In other cases the secretory and excretory systems do their work imperfectly, thus permitting the presence of waste substances in the body that are dangerous to the system.

The physiology of alimentation is most important, therefore, in order to reach an ideal conception of food in its purity and its adaptability to the system, and in relation to the processes through which the food must pass in order to be made ready for assimilation to the body. Alimentaty derangements must be remedied, therefore, along two lines either on the basis of proper diet, or on the basis of proper alimentary actions. How does nutrition of the tissues take place? All the tissues of the body receive their nutriment from the blood that circulates freely in all tissues. To this we must add the oxygen brought into the system in respiration. The proper food elements in connection with the blood depend upon the principles of dietetics. Food, whatever the food may be, differs very materially from the blood and its elements. Hence, certain substances, either in solid or fluid form enter the body to be subjected to certain physical and chemical changes which constitute the digestive process.

In order to the carrying on of digestion, certain actions and processes are necessary for the breaking up of the food, and for its passage to the various glands which secrete fluids, into contact with which food must be brought in order to prepare it for absorption. When it has been acted upon by the various juices, it appears in the soluble form of chyme so that it can pass into the blood or into the lacteals. The chyle passes through the mesentery to the receptaculum chyli, from whence it passes along the thoracic duct to the blood. In this way the blood receives by absorption new nutritive supplies to which is added the oxygen from the respiratory process. For the process of blood formation, blood corpuscles are introduced from the blood glands, these blood corpuscles being held in the fluid. Under the mechanism of the circulation the blood is carried throughout the body bringing these nutrient elements to the different tissues of the body. The blood is receiving new supplies of nutriment, and also eollecting the waste matters from the tissues. These waste elements cause the blood to become impure, so that these impurities require to be given off in the form of excretion. The organic functions of the different organs, although distinct, are not independently so. The blood, for example, is a bearer of oxygen and the nutrient matters, at the same time being the bearer of the waste matters. Similarly the liver is the organ in connection with whose cells the formation of the bile takes place, and also the metabolism which is connected with secretion. In the discharge of all these functions there is the setting free of energy in the form of heat and of mechanical work, all the organs of the body being concerned in this liberatiou of energy and heat. In this way nutritive processes lie at the basis of all the activities of the body mechanism and are therefore of great importance.

SECTION II. Diet.

As the body is made up of various proximate principles it is evident that the food which is to nourish the body, must contain or yield similar proximate principles.

The parts of the food which are digested and used by the body are called alimentary principles. An adult, in order to maintain life and health, must use a certain quantity of food daily. The waste is constantly going on in connection with the physical and psychic changes depending upon activity. In a person who is growing a larger amount of food is necessary in order to

furnish matter for the new forming tissues of the body. As the food stuffs are in an insoluble form and differ from the matter of the body tissues conversion requires to take place in order to fit them for use in nourishing the body. The food is subject to great variations from place to place and from year to year, but when all these complex foods are analyzed they are found to consist of certain specific substances which have been reduced to classes. In order to estimate the nutrition value of food it must be analyzed in order to find the constituents contained in it. In order to understand the digestive process we must carefully consider the chemistry of the foods made use of. The proximate principles of the food are: 1st, Water. Too little water in the system causes thirst and too much water causes plethora. Water may be regarded as the medium in which the various chemical tissue changes take place. The amount of water present in the system appears to influence the activity of the tissue changes, for by increasing the amount of water taken in, the amount of nitrogenous waste matter excreted is increased to an extent beyond that which can be explained by the increase of fluid, increasing the facilities of excretion. Water should be clear and free from odors. It should be fresh and palatable, due to the presence of salts and carbonic acid. Spring water is rich in oxygen from the atmospheric air and carbonic acid from the earth. These are said to exist to the extent of 10 to 20 C C of oxygen and 5 to 25 C C of carbonic acid per liter. Distilled water is tasteless. Rain water has no saline substance and hence it is soft, containing carbonic acid, ammonia and some other acids. Water from certain springs contain large quantities of carbonic acid, sulphur, etc.

In water there are mineral substances including the carbonates, sulphates and chlorides. The hardness of water depends upon the lime and magnesia contained within it. Good water should not have more than 20° of hardness, that is, 20 parts of lime to 100,000 parts of water. Water containing organic matter should not be used. Micro-organic subrtances may be found also in the water. Water is absolutely essential to the body as the tissues must have a certain quantity of water to sustain life. If the water falls below a certain quantity which varies in different persons and in different conditions there is a waste in the body.

2d. Salts. Mineral substances are necessary in the foods in order to promote the nutritive processes and for the purpose of nourishing the body. When these salts are absent the health is endangered. The chief salt is chloride of sodium found in all the tissues of the body and in its fluids. In the body excretion it is estimated that from 18 to 20 grams of sodium chloride are excreted daily, and this amount should be supplied daily to the body. If a diet consists of no salts albumin is usually found in the urine. There is not sufficient common salt in the food stuffs, hence, salt must form an element of food. If potassium chloride is used instead of sodium chloride the urine if found to contain very little sodium chloride, the blood and tissues retaining it. Part of the sodium chloride also goes through a chemical change that supplies chlorines in order to form hydrochloric acid for the gastric juice. Potassium salts are also necessary in food. These are found in the blood corpuscles, muscle and nerve tissue, while the sodium salts are found in the liquids. Small quantities assist the circulation of the blood raising the blood pressure and assisting the heart in its normal contractions. Lime salts are also necessary for the nutrition of bony tissue. Iron is found in connection with hæmoglobin of the blood. Most of these leave the body in the same form as they are introduced, playing some important part in the process of nutrition, and then being excreted. These are of value not so

much for the chemical changes which they are subject as in connection with the metabolism of the body.

3d. Carbo hydrates. Among these are starch found in potatoes, arrowroot, cereals and in the leguminous vegetables. It is found in small oval granules, possessing different degrees of resistence to water penetration. Cane sugar is found in connection with the cane and the beet, and in some vegetables such as carrots, turnips and watermelons. Grape sugar is found in fruits, in honey, in wine and beer. In addition to these, there is milk sugar, muscle sugar and cellulose. All the carbo-hydrates become absorbed as sugar in digestion. If the diet is rich in carbo-hydrates, the urine excreted is lessened, because the carbo-hydrates are easily oxidized; hence they are used up first by the body. They have no nitrogen and they are destroyed in the body, and from them energy is set free which we find in heat and work. They form the bulk of all diet.

4th. Fats. The fat in animal food consists of three substances, stearin, palmitin and olein; the latter representing the fluid fat, such as oil and the two former, the solid fat such as butter and lard. If an animal is fed on fat alone, the excretion of urea is less than if the animal receives no food at all, indicating that if much fat is present the proteid substances are less likely to be changed in metabolism. There is no nitrogen in fat and hence the fats have greater value as a source of heat and energy than the carbo-hydrates for they are less easily digested and less easily subjected to destruction in the body. Their chief physiological value is, that the fat can be stored up in the body.

5th Proteids. There are two kinds of albuminous substances. (a) Animal such as caseine (milk) myosin (muscle) and albumin (egg and blood.) (b) Vegetable, such as the albumin in wheat and legumin in peas and beans. Albuminous matter is not found so largely in vegetables as in animals. These albuminous substances form the chief substance in the metabolism of nutrition because there is a large amount of proteid in the blood and in the tissues. The proteids whether animal or vegetable are practically the same. Physiologically they furnish the matter for the formation of new tissue and for the repair of old tissue and also as a source of body energy. Because the proteids consist of nitrogenous substances, since the fats and carbon hydrates do not contain nitrogen. Hence proteid is necessary to form new tissue. If the food contains no proteid the tissues would soon waste, hence the proteids and water are the most essential for existence and the other foods are accesories to these. Among the proteids are classed also the albuminoids. One of the chief albuminoids is gelatin. It is not found in the raw foods but we find it in such cooked foods as soup. Like the proteids they contain nitrogen. They cannot, however, take the place of the proteids, their value being that they are nitrogenous, although differing considerably from the pure nitrogenous foods.

6th. Gases. Oxygen may be regarded as a food. Its passage into the blood and the tissues takes place in respiration.

7th. In addition to these certain condiments and beverages are used as food accessories. These stimulate the appetite and promote digestion if taken in moderation and under proper restraints. Alcohol, although in one sense a food, is not a very suitable food. Liebig states that alcohol is decomposed in the blood into ethyl, acetic acid, oxalic acid, CO_2 and H_2O. There is a small quantity exhaled through the lungs and excreted by the kidneys. It is said to be oxidized to the extent of 96 per cent, this oxidation producing heat. It also diminishes heat by interrupting the metabolism

in the tissues and lessening the oxidation of fatty substances and carbo-hydrates finally reducing the animal heat. It diminishes proteid metabolism as is evident from the diminution of urea excreted. In small quantities it excites the digestive mucous and also acts as an excitant by diffusion of circulation and the nervous system. In digestion it is not only unnecessary, but hurtful unless used in very small quantities.

The wines contain in addition to alcohol, pigments and organic acids. The character of the wine depending upon the acid that prevails. In wine there is also sugar some traces of proteids and gum. In brandy there is in addition to alcohol œnanthic ether, in rum butyric ether which gives it its odor, in gin juniper oil and in whisky when free from alcohol there is a malt flavor. In the malts we find alcohol, sugar, glutin, dextrin, together with bitters aromas and salts. In beer we find 70 to 80 per cent of water, 2 to 10 per cent of alcohol and 2 to 5 per cent of sugar, 2 to 10 per cent of dextrine and ½ to 1 per cent of carbonic acid. From the hops it derives its bitters, fats, lactic acid and salts. Vegetable acids such as vinegar and acid fruits taken in moderation act as a stimulant in salival and gastric secretion being changed into carbonic acid in passing through the body being excreted as carbonates in the urine. The stimulant condiments taken in small quantities such as pepper, mustard, spices, etc., locally stimulate the mucous membranes and aid the flow of saliva and gastric juce, but digestion may be performed without these. Tea, coffee, cocoa, coca all contain an active alkaloid along with other substances acting as a stimulant upon the nervous system actively increasing the ~~sections~~ and lessening the activity of the waste of tissues. These alkaloids are all related to xanthin. They also contain other substances which are of Physiological value. For example, coffee has a large quantity of aromatic substance, tea a large quantity of tannin and cocoa a large quantity of fat and albumin. Tea also contains iron, maganese and sodium and etherial oil. Coffee contains potassium salts. Tea and coffee act as stimulants to the nervous system and have no after effects of depression like alcohol, relieving feelings of fatigue. This is especially true of coca, the extensive use of which enables persons to undertake long and fatiguing journeys.

A healthy diet must first contain all the proximate principles found in the body or substances capable of yielding all these proximate principles. 2d. Include a sufficient proportion of these substances varying somewhat with the age and condition of the person, the work performed and the climate. 3d. Have a certain sapidity or flavor, in order to promote the appepite and digestion. 4th. These substances must be digestible in order to be nutritive, the indigestible substances being not only lacking in nutritive value but producing an interference with the digestive and excretive organs. Life cannot be sustained upon one of the proximate principles or upon food yielding only one of these principles. There are experiments that have been made in which animals and also human subjects have been fed upon a single proximate principle the result being fatal or injurious to health. A normal diet is one found containing a certain proportion of food of a certain composition necessary for the maintenance of life. Experience and usage have led people to adopt certain diets, and the results of their experience furnish the only means of selecting a proper food diet on a correct basis. Food includes those liquid or solid substances necessary for the nutrition of the body. In the body tissues certain processes of metabolism are necessary to sustain vitality. Chemical changes take place and certain substances are formed which are thrown off as waste matters. This daily

loss takes place in connection with the lungs, the kidneys, the skin and the other excretions. Food is necessary to make up for this loss. In the case of an adult working moderately, there is a daily loss by the lungs of about 900 grams of CO_2 or 245 grams of C; by the skin of about 9.15 grams of CO_2 or 2.5 grams of C; by the kidneys about 30 to 36 grams of CO_2 or 9 to 10 grams of C; in the fæces about 15 to 20 grams of C. This represents a total of from 270 to 280 grams of C excreted from the body daily. In the urine there is about 30 grams of urea excreted daily or 14 grams of N. In the other nitrogenous matters excreted from the body there are about 5 grams of N excreted daily, making a total of about 19 grams of N excreted daily. There are also excretions of O and H and various salts, but the chief elements are the C and N because food from a dietetic standpoint depends largely upon these elements. This represents a total loss of about 1,000 grams of matter aside from the water that is thrown off. In addition to this energy is being expended, this energy assuming the forms of motion and heat. This energy is estimated as amounting to over five million foot pounds. The energy represented by the heart action daily is about 50,000 kilog. meters by the activity of the muscles of respiration 12,000 kilog. meters, by the activity of the ordinary muscles 125,000 kilog. meters and the body heat 620,000 kilog. meters representing the total of about 807,000 kilog. meters of energy exhausted daily. This energy must be compensated for by the food supply and by the O of respiration. The changes taking place in the body result in the setting free of energy in the form of heat and mechanical work. The larger amount of the energy takes the form of heat. Even during the inactivity of the muscles, these chemical changes are constantly taking place. In the contraction of muscle more than ¾ of the energy assumes the form of heat, the remaining ¼ taking the form of work, even a part of this latter being in the case of work also converted into heat. This heat supply arises in connection with the oxidation of the food materials, this oxidation taking place in connection with the O absorbed, combining with the CO_2 and the H_2O.

The energy of the body thus converted takes the form of potential energy, these foods being derived originally from plant life built up in connection with the energy of heat-producing bodies, such as the sun. This potential energy under the influence of active body metabolisn becomes kinetic energy. The combustion of foods outside the body gives an approximate estimate of the amount of energy available in the case of certain food. In connection with any substance, it is necessary to determine the energy of the foods as admitted to the body, and also the elimination of waste from the body. This must be replaced by metabolism between the food and the O of respiration. The food supplied to the body during the process of alimentation has, therefore, a most important bearing upon life, functional capacity and health.

The first law of dietetics that we have already referred to, that a suitable diet must provide the proximate principles of the body or foods that will produce these. This is true equally for the plants and animals for civilized and uncivilized people. The general dietary principles have been derived from experiments upon the feeding of animals. In the normal adult the chief consideration in dieting is to provide nitrogenous and non-nitrogenous matters with sufficient salts and water to sustain the body condition. If proteid substances are used alone, a much larger proportion must be used than in the case of the mixed diet. It is questionable if in the human subject life could be long sustained normally, on such a diet on account of the

greater activity of the digestive process in digesting proteid alone and on account of the greater increase of activity in the excretory system. Hence, the general conclusion from this standpoint of hygiene is that there must be a mixed diet consisting of proteids, fats and carbo-hydrates. The ratio between these three chief food elements depends upon the experimental value of the different kinds of food. It is on this basis that the iso-dynamic equivalents made use of by Moleschott are estimated. Voit estimates the ratio of nitrogenous to non-nitrogenous foods as from 1 to 5, this calculation being based on the amount of food in the dry condition. In addition to this the food may be digestible or indigestible. Some foods digest easily and others with difficulty. This can only be determined by experiments in the use of foods in animals. This gives to meat food great nutritive value because only a small per cent is lost, whereas, in vegetable food usually a large per cent escapes digestion and absorption. Various attempts have been made to fix an ideal diet that would meet all possible necessities of the bodily system. Moleschott taking as his basis the daily loss of an individual as we have found it already amounting to about 19 grams of N and 280 grams of C has suggested as a dietary 120 grams of dry albumin, 90 grams of fat, and 350 grams of carbo-hydrates, making in all about 19 ozs. of solid food. According to the estimates of energy on the basis of the colorimetric method, this would produce by oxidation normally a little over one million kilog. meters (one kilog. meter equals 7.233 foot pounds) yielding more than sufficient energy to sustain life, on the basis of the energy expended as given before, considering that complete oxidation does not take place in the body. Experience has shown that dietary variations are necessary for different people, according to their employments or manners of life. Those actively employed in occupations calling for muscular exertion require more food than those engaged in the lighter occupations. This has been brought out chiefly in connection with prisons and reformatories, much larger diet being required when active work is performed.

An ordinary diet of solid food should contain proteid 120 to 130 grams, fats 80 to 90 grams and carbohydrates 350 to 450 grams, and salts 30 grams, representing a total of from 580 to 700 or a little over 20 to 25 ozs. of solid food. In addition to this about 20 to 25 ozs. of water is necessary in connection with the food for cooking purposes, as ordinary food contains about one-half of its weight fluid and from 70 to 80 ozs. of water in addition as a special food element. According to the scientific estimate, a soldier is furnished daily 18 ozs. of bread, 20 ozs. of meat and 16 ozs. of vegetables in addition to 70 ozs of water, and some coffee as a stimulant. The analysis of the composition of various food stuffs indicates that bread, oat meal, peas, cheese, beef, including mutton and veal, fish and eggs are rich in proteid. Rice, arrowroot, potatoes are rich in carbohydrates. Butter, cheese and pork are rich in fats, these being arranged so far as the composition is concerned so that deficiency in one can be made up by others. There are said to be two methods of selecting a proper food diet. 1st. To find out the per centage composition of the articles made use of, estimating the amount by weight required to yield the necessary proximate principles. 2d. To make a selection of food on the basis of Moleschott's estimate that 19 grams of N and 280 grams of C are necessary to supply the daily loss. In this last case it is necessary to estimate the proportion of C to N in the various articles of food. The food is not taken in the form of the proximate principles but in combined articles of diet like bread. In order to estimate the ideal diet it is necessary, therefore, to estimate the

proximate principles as found in the various composite foods. In order to have an adequate measure of the vital necessities it is also necessary to estimate the dynamic value of the different foods. This can be done by the calorimetric method in which an estimate can be formed of the amount of heat generated from a given weight of a certain substance or substances, taking into account the fact that complete oxidation does not take place in the system in connection with most of the substances, the amount of energy furnished being less than its estimated amount theoretically. Experiments in regard to the use of certain diets have confirmed these ideas in regard to the distribution of the food elements and their nutritive value. A normal diet therefore, consists of the three great food elements, proteid, fat and carbohydrates, the last being always in excess of the other two. The body may be sustained on the proteids alone, but this is at the expense of the body mechanism because more labor is necessary and the foods are more costly. The fats and the carbohydrates are nearer akin to each other, the fats being converted to sugar and the carbohydrates furnishing the fats necessary for the body when the fat is absent from the food.

In making an estimate of the amount of food necessary in a normal diet three additional circumstances must be taken account of. 1st. Age. 2d. Climate. 3d. The kind of employment. 1st. Young persons and those growing rapidly need more food in proportion to their size than adults, in order to assist the metabolism of the rapid bodily growth. Old people need less food than middle aged and active people, and females less than males:

	Proteids.	Fats.	Carbohydrates.
Children of one year..........................	20	30	60
Children of fourteen years........................	70	36	250
Adult (man)...........................	100 to 110	70	500
Adult (woman)...........................	80 to 90	60	400
Old people....................................	70 to 90	60 to 70	300 to 400

Some think that the size of the body to a large extent determines the amount of food necessary. In general it is said a small body requires less food, but this is subject to the same exception as in the case of body heat, namely: That the metabolism is really greater in the smaller body, the surface being relatively larger, and therefore demanding more food for body metabolism. 2d. Climate. The chief element in climate is that of the temperature. When the body is exposed to a cold bracing atmosphere, the body metabolism increases on account of nervous stimulation producing an increased appetite.

Greater amounts of food are therefore required in cold climates. As the metabolism of the body uses up more carbonaceous matter the food rich in fat elements is the most suitable. This leads to the use of large proportions of fatty substances which by the oxidation process becomes converted into heat. If the bodily system is subjected to a high temperature the metabolism is lessened, although the results are less noticeable in this direction than in the case of cold, chiefly because the temperature of the body tends to maintain its normal heat chiefly by an increase of the amount of heat lost. This leads to the conclusion that more food is required in the hot climate than in a temperate climate, chiefly fluid in character, in order to compensate for the continuous loss by perspiration. Differences in climate to a large extent, however, are compensated for by artificial arrangements, such as clothing, and the supply of heat by air as in the heating apparatus of the house. This, however does not wholly compensate for the metabolic changes and hence in hot regions as com-

pared with the cold the normal diet will be maintained about the same, except that in the hotter regions an increase in the carbo-hydrates and in the colder regions an increase in the fatty substances taken as food is required. 3d. The work done by different individuals is the last element to be considered in connection with the determination of diet. The amount of work modifies the amount of food required in the case of those engaged in the lighter avocations as compared with those in active employments. One who is engaged in hard manual labor requires a larger and more varied supply than one who is not active muscularly, particularly as the amount expended in energy is not taken from the amount of heat liberated, the increased energy in the work being accompanied usually by an increase in the heat set free. Muscular metabolism does not necessarily require an increase in the proteid matter. In muscular labor the muscular condition and capacity, at least from the standpoint of available energy, must be considered, but the capacity for work depends upon the other organs of the body, particularly the nervous system, the lungs and the heart, the nervous system perhaps more drawn upon for energy than any other part of the body. Therefore, whatever diet would be suitable for the body normally would also be of the greatest advantage during muscular activity, provided the activity is increased in such proportion as to meet the general drain upon the system. In the case of mental work this is even more true for the expenditure of energy in this case is minimal except in so for as it bears upon the loss and the increased loss in the entire system. The close relation of all parts of the body is brought out very clearly in the effect which severe mental work has as it draws upon the metabolism of alimentation. Hence the most suitable diet for brain work is not one that would stimulate or nourish the brain because this would result in more or less irritation, but a diet that will keep active the juices of the body in connection with digestion and secretion. In making a selection of food we must consider first the amount of energy that may be yielded by the materials. This represents certain proteids, fats and carbo-hydrate substances. 2d. This energy must be present in such form as to be rendered easily available, in other words the food must be digestible and this digestive process must be such as not to interfere with metabolism of the system. But a substance really valuable for nutrition is one that can be easily assimilated to the system. Various experiments have been made in order to discover what per centage of the food used remains undigested and hence unappropriated by the system. This percentage, of course, depends upon the manner of cooking, on the individual capacity and to a certain extent upon the nature of the meal of which it forms a part. For example, in rice and white bread it is estimated that 4 per cent. in meat and eggs, 5 per cent; in Indian bread or corn, 7 per cent; in milk and peas, 9 per cent; in potatoes 11 per cent; in black bread 15 per cent remains undigested. This would represent the amount of these foods unnutritious and disadvantageous to digestion.

In addition to this the process of digestion may vary in the case of different food stuffs. The same substances found in the different articles of food may even in the alimentary canal pass through changes that are quite different. Proteid matter may be broken up into leucin or changed into peptone ; hence, digestibility of food means not only the amount relatively taken up in the alimentary process, but the nature of the changes that take place during the alimentary process. Hence the chemical composition of food does not furnish an answer to the physiological question of its value or the value of its component elements. Food substance may be either animal or vegetable. The proteids from the animal and vegetable source seem to pass through the same or almost the same changes in the alimentary process. The same may be said of the

fats and extractives. Hence, from a physiological standpoint all that can be said as to the relative merits of vegetarian and animal diet bears upon the question of the quantity of the proximate principles and the proper proportion of these principles in animal and vegetable diet. Various experiments have been made in the use of a strictly vegetarian diet. As a result it is found first, that a much larger vegetarian diet is necessary to yield the same amount of proteid referred to as a normal diet, namely, 120 to 130 grams. However, it has not yet been definitely settled how much proteid matter is absolutely necessary in order to sustain life. 2d. In vegetarian diet there is a marked increase of the carbohydrates and a diminution of the amount of fats. This seems to be a disadvantage to the system, kept up continuously for a length of time. 3d. In the vegetarian diet a large proportion of the food is indigestible and hence is lost to the system, being given off as waste matter. The waste, therefore, is more in amount in the vegetarian diet than in the animal diet. As excretion is one of the active functions of the body a certain amount of excretion is necessary in order to sustain the normal function and assist in metabolic changes. This does not seem to be compensated, for however in the case of vegetarian diet since a larger demand is made upon the alimentary system in the form of labor and the increased volume of diet passed through the system lays the system open to more foreign substances which may materially affect its vitality. For these reasons vegetarian diet would seem to be less satisfactory than the mixed dieting that includes animal food.

In the case of the human subject there is not needed any special dieting for the purpose of increasing the amount of adipose tissue. The nature of the food has less effect in this case than the general characteristic of the individual animal organism. The same dieting in the case of two persons may produce opposite results; one person becomes fat and the other lean. The chief fat producer is the carbohydrate. In the case of animals fattened for butchering, this is done by converting cheap vegetable carbohydrate into animal fat. This process is aided by resting the system so as not to exhaust the energy of the system unless to the extent necessary for the metabolism of the body. Anti-fat treatments are more important physiologically. This may be accomplished by increasing normal dieting the amount of proteid and lessening the fats and carbohydrates. The reason of this is found in the fact that proteid matter increases the body metabolism, more rapidly destroying the proteid matter and hastening the oxidation process. The Banting plan is to increase the proteid diet to such an extent as to exclude all or almost all fat and carbohydrate substances.

This is, however, unsatisfactory and even perilous to the functional life because it requires such an increased activity on the part of the organism to decompose and get rid of excessive proteid that there is danger of collapse. To diminish the fats and carbohydrates at the same time to increase the amount of proteid together with an increase in the bodily exertion, so as to set up and continue freely the metabolic processes is the most satisfactory method. Daily exercise even to the extent of fatigue aided by Osteopathic treatment, to aid digestion and promote the metabolic processes, will materially help this by producing a very large metabolism. In body metabolism a number of conditioning circumstances require to be considered. Muscular effort increases food consumption, but it is a matter of dispute what food element is affected. It has been pretty generally agreed that muscular activity draws not only upon the proteid matter, but in some cases almost entirely upon the non-proteid substances. If the supply of food is abundant, particularly of non-proteid, that is the fats and carbo-hydrates, there will be no increase, or at least, only a very

small increase in the proteid metabolism, during active muscular effort. In the case of CO_2 it is found that a much larger amount is given off during muscular activity than during comparative rest. If it is true that there is an increase in the amount of nitrogenous matter excreted and a very large increase in the CO_2 discharged from the body, then the energy of muscular activity must arise from non-proteid matter. The muscle itself is a proteid substance but the changes taking place in liberating the energy are largely, if not wholly, confined to non-proteid matter. In muscular activity there is a large consumption of glycogen, or of the saccharine, derived from it. It has been shown that a muscle subject to fatiguing labor demands much more sugar, the power to do severe muscular work being increased by the consumption of large quantities of sugar until the non-proteid elements are exhausted, when the demands upon proteid matter increase. During sleep when the muscles are much less active or resting, having lost to a certain extent, their normal muscular tonicity, the CO_2 discharged and the O absorbed, are very much lessened, while there is no marked change in the metabolism of proteid matter. In the case of animals deprived of food, the metabolism depends upon what is found in the body, consisting of stored up fats and carbo-hydrates, especially the sugar. The sugar is first exhausted, and later the animal lives upon its own fat and proteid. It is found that in an animal feeding upon its own substance, the greatest loss is in the muscles, whereas, the largest consumption is in the fat, which is found to be almost entirely gone after death from starvation. It has been found on examination of animals that died from starvation, that almost no appreciable loss had taken place of the heart, the brain and the spinal cord, although these organs were constantly active during life. They sustain their life, however, at the expense of the other tissue substances. In the case of energy assuming the forms of heat and work done, the supply is derived from metabolism of proteid, fats, and carbo-hydrates which become oxydized under the influence of O, CO_2 and H_2O, being formed and excreted from the body. Thus, the energy derived from the food is determined by comparing the food taken into the body with the excretions from the body. The process of oxidation is a complex one, involving the liberation of energy together with the formation of urea, CO_2 and H_2O. By the combustion of the different elements of the food substance, a ratio is formed representing the interchange taking place in the liberation of energy called the isodynamic equivalent. This ratio between fats and carbohyrates is put at 1 to 2.3. The object of the food supply is to furnish to the body sufficient proteid and non-proteid matter together with salts and water to sustain the body balance between proteid and non-proteid matter.

In the case of man it is doubtful if this body equilibrium can be maintained by the use of proteids alone so that an average diet for the human being must be composed of proteids, fats and carbo-hydrates. The normal ratio between proteids and non proteids necessary for daily diet is placed at 1 to 5 in the solid material apart from the necessary quantity of water found in connection with the substances used and the quantity of water necessary for the body. In order to secure a proper diet we must consider the proportion of those substances in the different articles of diet, pre-supposing that these substances are digestible and that account must be taken of digestibility from the standpoint of the individual organism. In the case of a healthy person normally active experience aided by appetite may be taken as a safe guide. In abnormal conditions the regulation of diet depends upon Physiological and Pathological conditions. In milk of an ordinary kind we find about 87 per cent water, 3.4 per cent of proteid, 4 per cent fat, 5 per cent sugar and a small per cent of salt, .7, including potassium phosphate and calcium phosphate with a small

amount of chloride of potassium, sodium chloride and iron. Milk is a good diet for growing persons but is not sufficient for adults, because the balance of the nitrogenous elements cannot be sustained on such a pure diet. Cream butter yields about 87 per cent of fat, 8 to 9 per cent of water and .75 or .80 per cent of albuminous substances. When combined with foods that yield proteids and carbo hydrates it is very valuable as a diet. Butter milk is milk deprived of its fats, but contains sugar, casein and salts. Cheese contains fat and casein, from 10 to 20 per cent of the former and 25 to 30 per cent of proteid. It is valuable as an addition to other foods poor in proteids and fats. Animal meat of average leanness contains about 75 per cent of water (fowl about 70 per cent and pork 72 per cent); of proteid 20 per cent (fowl 22 per cent and pork 19 per cent); of fat 5 per cent (fowl 4 per cent and pork 6 per cent; of carbohydrate .7 per cent (fowl 1.3 per cent and pork 6 per cent.) The flesh of fowls and birds is richest in proteid. Raw flesh finely grated is almost wholly digested but its value for nutrition may be counteracted by the introduction into the body of foreign living bodies endangering life as in the case of trichinosis. Meat may be prepared in various ways by roasting, stewing and boiling. Meat should be cooked to a temperature within the meat itself ranging from 56° to 70° C. Salted meat loses a small per centage of proteid, of the extractives and of phosphoric acid passing into the salt brine. The amount lost, however is small unless where the meat is kept in brine for a long time when the potassium salts are lost to a large extent. The flesh of young animals is richer in gelatin, the variation being according to Liebig in veal 50 parts in a thousand and in beef 6 in a thousand. Meat roasted openly before a fire develops a layer on the surface keeping the juices inside. In the process of roasting, about 25 per cent of the weight is lost. If meat is placed in cold water there will be dissolved out of it a small per cent of proteid and extractives and most of the saline matter. If beef is boiled then the salt and the extractives with gelatine are found in the fusion. Even after long boiling there remains in the meat about 20 per cent of the salts and about 15 per cent of proteid. To prepare what is called beef tea, the meat should be placed in cold water and gradually boiled. By placing the meat suddenly in hot water there is a coagulated layer formed around the meat, thus preventing the juice from being dissolved out of the meat. Beef tea is nutritious because it contains salts, gelatin extractives and a small quantity of proteid. Its chief value is that of stimulation due to the extractives; its nourishing quality being found in the gelatin, fat and albumin.

In Liebig's meat extract there is about 20 per cent of water and 80 per cent of solids, its action being rather stimulating than nourishing, due to the presence of phosphate of potassium. Eggs are found to contain much nutritious matter, about 27 per cent of solid and 73 per cent of fluid. The chief constituent of the solids are albumin, vitellin to the extent of 3 per cent and palmitin, olein, cholesterin and lecithin about 11 per cent together with, about 1 per cent of the salts of potassium and choloride and a very small proportion of iron and sugar. As found in the egg these substances are very easily digested. When hard boiled they should be boiled for at least 20 minutes slowly. They should be finely grated so as to come readily into contact with the gastric juice. They are more easily digested if soft boiled, poached or raw. Vegetable foods are less easily subjected to the digestive juices on account of fact that the nutritious elements are bound up with cellulose and combined with large quantities of indigestible matters. The proteid in vegetables does not differ much from animal proteid. The salts, however, are different, being chiefly those of potassium and magnesia phosphates. When the

cereals are broken so as to divide the cellulose it is found that the flour contains about 12 or 13 per cent of albumin, 65 to 67 per cent of carbohydrates, the bran being very indigestible on account of the large per cent of fibrous substance, 30 per cent. The flour when made into bread, in the case of white bread, contains 35 per cent water, 7.1 per cent of albumin, 1 per cent of fat and 55 5 per cent of carbohydrates and 1 per cent of salts. Indian corn bread is rich in carbohydrates and poor in albumin. Barley and oat meal flour are nutritious on account of the combination of albumin and carbohydrate. Bread consists of a mixture of flour with water under the influence of a ferment. By fermentation the starch is converted into dextrin, CO_2 and alcohol; by the formation of gas the bread becomes looser and lighter in formation. When the bread is baked in a high temperature fermentation is arrested and the bread be comes very digestible. Each adult requires about 1½ kilog. of bread to furnish the necessary proteid matter. Among the leguminous plants and vegetables, peas and beans are said to contain over 23 per cent of albumin, 50 per of carbohydrates, 1½ per cent of fats, while potatoes contain 75 per cent of water, only 2 per cent of albumin and 20 per cent of carbohydrates. Rice and potatoes being very deficient in proteid, large quantities are required to be taken to be of much value in nutrition, 2 kilog. of rice and 4½ kilog. of potatoes, as the proportion of carbohydrates is large, the excessive use of these is liable to produce acid ferments that interfere more or less with digestion. Along with this when used in moderation there should be used some foods rich in albumin such as fish and eggs. The vegetables, cabbage, cauliflowers and turnips are rich in the potassium salts, although not very nutritious as foods and hence form a good combination with corned meats which are deficient in potassium and rich in the sodium salts. These elementary foods are not suitable for use in their raw condition, hence, cooking is required in order to make them easily digestible, and to give to them a flavor. In cooking food, water, condiments and heat are the three necessary adjuncts in the preparation of food for coming into close contact with the bodily juices and assimlation into the system.

Food, we have seen, includes all that is necessary for the sustenance of the body. All foods originally spring from the earth, so that while we distinguish between an animal and a vegetable diet, the source of food depends upon the same origin. In the passage from the inorganic to the organic, we find the process of preparation going on which ultimately brings the food nearest to the human system. This change takes place primarily in the vegetable kingdom. All the vegetables are not suitable for food and many of them are poisonous. Even in the same plant all the different parts are not equally useful, hence man requires a knowledge of these plants, their properties and their adaptability for human use. Some portions of the vegetable kingdom unsuitable for man's use are well adapted for the food of animals, and thus in the economy of nature, the lower serves the higher nature providing a sufficient amount and variety for all. The bee gathers the honey from sources inaccessible to man, and the cattle feed upon rough materials unfitted for human use, converting the food into tissuse, food easily capable of assimilation to the human system. In this way the inorganic becomes adapted to man's necessities. The animals could not live without vegetables, each being indispensible to the life of the other. The vegetable is nourished upon the soil and the air, carbon being extracted out of the air and stored up in its substance so that it becomes the animal food. In the same way the vegetable lives and grows upon the waste of the animal kingdom, the decomposition of animal bones, the CO_2 exhaled from the animal breath furnishing the food matter of the vegetable life. The food substances

are either inorganic or organic, the former representing substances from the mineral kingdom, such as salts, and the latter representing the food derived from vegetables and animals. Nature thus provides for man a sufficient diet, sufficient both in quantity and variety, and if man fails to utilize the food thus furnished for his use he neglects the first law of existence, self preservation. The hygienic conflict between vegetable and anti-vegetable food is as foolish as it is useless, because nature designed both vegetable and animal food for man's use. Proper hygiene lays down the following rules:

1st. That an attempt to sustain life upon any one substance to the exclusion of others results in failure because the body is imperfectly nourished and life is thereby shortened. Dogs have been fed exclusively on a single food and have soon died of starvation. A donkey fed on rice alone died in 14 days. Dr. Hammond fed himself on 1½ lbs. of gum and on another occasion on 1½ lbs. of starch with water daily with the result that the fever increased to such an extent that in a few days he had to abandon this diet. Later he fed himself on 1½ lbs. of albumin and found that diarrhoeic conditions and the amount of albumin in the urine became so dangerous that he had to give it up on the ninth day.

2d. The absence of necessary elements of diet results in diseased conditions. It has been found that where persons have been deprived of vegetables for a long time, skin diseases like scurvy become prevalent. Where the food is poor it has a depressing effect rendering persons liable to all kinds of diseases. There is no condition that favors the spread of a plague so efficiently as a poor and unvaried diet. This is evident from the accounts we have of the poor and their scanty food during the great European plagues.

3d. A diet to be healthy ought to be varied. The same diet from day to day becomes, not only monotonous to the sense of taste, but develops unhealthful conditions. While we do not think that a diet should be purely vegetarian no diet should be without vegetables. Variety may be secured not only by the use of various foods but also by variety in cooking. The constitution is often undermined by the lack of variety.

Dr. Stark, one of the most promising of English Physiologists in the 18th century, became a victim in this way to experiments upon himself. For 44 days he lived on bread and water; for 29 days he took only bread, sugar and water, and for 24 days he lived on bread, olive oil and water, the result being that he died on account of the damage done to his constitution by limiting his diet to these simple foods. A sufficient variety in food and a sufficient quantity of food thus represent the two great essentials of a healthy diet. For an average adult there should be from 88 to 112 ozs. of food and water distributed as follows:

From 48 to 56 ozs. of water and salts; from 24 to 40 ozs. of bread, vegetables and fruits, and about 16 ozs. of meat and fats. This would represent a daily allowance of about 1-24 part of the body weight in the form of food. In regard to the variation of animal and vegetable food, Carpenter reaches this conclusion: that while "a well selected vegetable diet is capable of producing in the greatest number of individuals the highest physical development of which they are capable it may be affirmed with equal certainty that the substitution of a moderate proportion of animal flesh is in no way injurious, but so far as our evidence at present extends, this seems rather to favor the highest mental development."

If we consider the predominence of mind over matter this conclusion will represent a moderate principle in the nourishment of both mind and body. Dr. Richardson, of London, says that animal food should not be taken oftener

than twice daily and the amount of animal and vegetable food combined should not exceed 30 ounces daily. Animal food when eaten ought to be fresh and not under-cooked. There is no more fruitful source of disease parasites than meat underdone. This is especially true of pork, the muscles of which are infested with trichina spiralis.

HUNGER AND THIRST. Hunger is a sensation that is usually referred particularly to the stomach. Physiologically, however, it is due rather to a general want of the whole system. It is usually referred to the stomach because by supplying the stomach with food there is a feeling of relief. It would seem to depend upon the stimulation of the pneumogastrics in connection with the stomach and perhaps the alimentary canal or the intestines. The introduction of nutriment directly into the intestines or of concentrated food substances that do not cause a distention of the stomach or only a slight distention will satisfy hunger. This would indicate that hunger arises not from the stomach alone, but also from the other organs and tissues which demand nutrition. It is intimately connected also with the central nervous system. The division of the pneumogastrics does not produce any change in the feeling of hunger by way of relief. The use of stimulants like tobacco or alcohol lessens or at least puts off for a time its activity, possibly on account of stimulation imparted to the nerves of the stomach through the centers of the brain. The same effect may be produced by mental acts and states. In its origin hunger represents an appetite for food which is not painful. If continued, however, it becomes painful. Hunger is thus one of the forces of nature which tend to the preservation of the body life and indicate the necessity for diet.

Thirst is referred usually to the palate and pharynx representing a local condition of the mucous of the posterior portion of the pharynx. The section of the nerves which supply the pharynx, the pneumogastric, the glosso-pharyngeal and the trigeminal does not diminish thirst. This condition of thirst may originate in the lessening of the quantity of water in the blood or from the stoppage of certain secretions under the influence of certain chemicals, for example, belladonna. It is due to the general want of the tissues and can be relieved by the introduction of water into the blood vessels or into the alimentary system or by the submersion of the body in water. For how long a time an individual can live without food or drink is not known. This will depend upon a variety of circumstances including bodily condition and the amount of waste in the bodily substance, together with the age, condition of life and the surroundings of the body. Normally entire abstinence cannot be sustained longer than 8 or 10 days. This may be extended if water alone is supplied, although in extraordinary circumstances this period has been prolonged for 40 and even 50 days. The entire deprivation of food usually results in death after 20 days. Children and those rapidly growing succumb sooner than adult persons. With a supply of water life may be prolonged with a small quantity of food or even with no food at all, an animal surviving longer upon water than upon any of the other proximate principles. The entire deprivation of water usually results in death in from 6 to 10 days. Indians under the influence of drugs have been known to remain in a trance condition for many weeks. In cases where abstinence is prolonged the individuals become habituated to this condition, being almost like the hybernating animals. The cold blooded animals like the frog, have been known to live from 8 to 9 months without food. Dogs have been found to live a long time upon water alone, cases being on record in which dogs have lived for four weeks without either food or drink. In some cases there is an excessive appetite, this condition being termed bulimia. It is peculiarly characteristic of certain diseased conditions, such as diabetes and

in certain stages of fevers, especially during the convalescent period. The minimum of food necessary to sustain life, cannot be stated because this depends very largely upon the individual characteristics and upon the activity of life. Even the activity of life does not depend upon the amount of food, as individuals have often lived actively upon a very small proportion of food. It is generally stated that most persons take food in excess, this being one of the common causes of gastric derangements and dyspeptic conditions. Hence the advice of hygiene is to modify and regulate the diet in its quantity, as well as in the proper selection of food. During the starvation of the animal there is a constant body loss due to the using up of the tissues.

When the body ceases to receive nutriment it lives upon its own substance, the active organs losing rapidly. The fat stored up in the body is first exhausted, next the blood, its albumin being used up in the tissues. This is followed by diminution in the secretions, the urine becoming acid and the blood watery. The oxidations become less vigorous and the amount of CO_2 given off is diminished. The tissues then lose their power, become weaker in action, the central nervous system being the last to yield to the general disolution. What is the effect of a modified diet? Deprivation of water arrests the secretion and especially the activity of the kidneys resulting in death very soon Hence water must be taken in sufficient quantities The same is true of salts. If albuminous matter is cut off from the food supply there is a great diminution in the excretion of urea. This becomes more marked if the food is rich in carbo-hydrates. In this case the body metabolism, especially of the albuminous tissue is lessened in activity, less urea being excreted than if no food is taken at all. The carbohydrates in this case use the O supply of the body in the oxidation process, leaving but little of the O for the albuminous matter. If the carbohydrates are cut off and only proteids are given with plenty of water life may be sustained for a considerable period. If fat is given along with the albumin there are different results. If a small quantity of fat is given with a large quantity of albumin most of the albumin is lost in body metabolism. If a large quantity of fat is given and a large quantity of albumin, considerable albumin and fat are stored in the body. These facts indicate that a mixed diet is the preferable one, being more suitable to the bodily system, the proper combination of the different foods yielding most satisfactory results.

SECTION III. Fermentation.

Digestion consists largely of chemical changes taking place in the food in its passage along the alimentary canal. These changes are peculiar on account of the fact that they are accomplished by ferments to which the name of enzymes is given; the action of these being different from other bodies of asimilar kind. Many changes during the digestive process are simply fermentations. Besides the existence, development and reproduction of ferments, are intimately associated with certain diseased conditions. In the fermentation of fluid it becomes either clear or more muddy, throwing off gas and seething with the froth, these representing physical changes. Associated with these physical changes there are certain chemical changes represented by the alcoholic and other substances such as CO_2 found in connection with the fluid and given off from it. There is also a deposit at the bottom consisting of small organisms of a minute character, consisting of unicellar bodies representing the biological change. These processes, including the physical, chemical and biological, were all associated together as phenomena in connection with the ferment which is so called, from the fact that the surface presents the frothing appearance.

These processes must have been known from very early times. The first fact noticed was the frothing or the physical change. In early centuries alcohol, when formed by fermentation, was separated from the water by alchemy. Helmont first suggested that the gas thrown off was the same as we find in connection with oxidation processes, namely, CO_2. It was then found that by the dissolution of the sugar, CO_2 and alcohol were produced. Difference of opinion existed as to the substances formed from the fermentation of sugar, Pasteur being the first to differentiate the chemical substances in connection with sugar includiug alcohol, CO_2 succ inic acid and glycerine. It was early discovered that pure grape juice if boiled and kept free from air did not ferment, the unpurified and unboiled solution fermenting. It was not until comparatively recent times that fermentation was found to be due to certain vegetable cells which are found to grow and increase rapidly in sugar solutions. Many theories have been proposed to explain this phenomenon.

1st. The Berzelian theory was that it was due to catalysis or to the simple fact of the presence of the ferment in the fluid.

2d. The Liebig theory was that there existed no necessary relation between the fermentation and the existence of vegetable living cells. The living cells produce some substance which, as it acts upon the substances to be fermented, produces a motion among the atoms of the substances, giving rise to the boiling or frothing condition. This is simply an extension of the physical theory of Berzelius. Certain chemical changes are produced by the ferment resulting in vibrating movements. Liebig says that "Physiological action would be necessary for the production of these substances" in other words, the living organism undergoes a certain chemical change corresponding with physiological metabolism resulting in the formation of certain substances which produce molecular vibration. For a long time it was thus supposed that fermentation was purely a chemical process.

3d. In more recent times the question has been discussed largely from a biological standpoint; the ferment being caused by the presence of minute organisms. This has been accomplished, especially through the experiments of Pasteur, who spent considerable time in the attempt to cultivate these minute organisms. Thus, we have been led to the vital theory of fermentation according to which these represent germs of life, a particular form of life, or as Pasteur says, "fermentation is life without air," although it is admitted that these organisms assume two forms, aerobic and anaerobic, the one living through the presence and the other through the absence of air. It was first discovered that boiled grape juice if kept in a vacuum did not ferment, but if a single air bubble is permitted to enter, fermentation results.

Schwann admitted an air bubble through a red hot tube and found that no fermentation followed. He concluded that fermentation was due to something in the air and heat prevented fermentation by destroying the substance in the air; hence, physical and chemical conditions seem to favor the growth of the organisms from 20° to 40°C. assisting, above 60°C and below freezing point arresting it. Schwann then attempted to identify fermentation and putrefaction, finding that the air has the same to do with putrefaction as with fermentation.

Helmholtz proved that air is produced by the dissolution of a compound by means of electricity, the air thus produced does not cause fermentation. By placing a bladder filled with grape juice inside a vat of fermenting juice the fluid in the bladder did not ferment, the producing

cause being unable to pass through the wall of the bladder. From this and similar experiments it is evident that the organisms in the air are the cause both of fermentation and putrefaction. At this point Pasteur began his researches which have immortalized his name and produced a revolution in the scientific world. He found that each form of fermentation was produced by a different ferment. The alcoholic by the yeast cell, lactic fermentation by lactic acid, etc. He then began to cultivate these organisms in certain fluids which seem germane to their life so that he could localize certain organisms with certain fluids. He found that the ferment producing the butyric fermentation could live and grow in a fluid mixture of certain minerals with sugar, the presence of free air interrupting the fermentation. He found that this applied to some of the other fermentations. It was this that led him to the conclusion that most of the ferment organisms may be ærobic or anærobic, that is, live in the presence or absence of air, but that it is while it is anærobic that it does the fermentation work. When it receives free air it grows and develops as in the case of molds found on the surface of exposed foods, but when free air is excluded it draws O from the substance in which it exists and in this way produces fermentation. This does not mean that these organisms can live without air, for they can produce that air necessary for their life inside the substances in which they are found. They can live without free air as Pasteur has said, extracting sufficient O from the substances such as sugar.

Engleman has pointed out that some of these organisms gather close to an air bubble while others move away from the air bubble. There are some, however, that require O, as the bacteria aceti. Pasteur's final theory is that some O is necessary at the beginning of fermentation, but that when begun free O is not necessary. By these experiments the biological theory of fermentation has been established. Some organisms have been identified in connection with lactic fermentation, the acetous mannite and urine as well as putrefaction and fermentation. Although the fermentations are different and also the ferments, some of the productions of fermentation are alike, for example alcohol; some claim that the increase in the minute organisms in the substances is not the cause of the production of fermentation but the product of fermentation. It has been proved, however that if the fermentation germs do not pass into the fluid, fermentation may be prevented, so that it is possible to completely sterilize certain fluids and substances and so remove anything that could cause fermentation. The manner in which these ferments act is unknown, although it is supposed that these minute organisms produce a kind of ferment which acts on the substances under the process of fermentation. This action is supposed to take place not directly but by reduction. In this case, of course, the absence of O would be characteristic. If O is present it is more likely that the process is one simply of oxidation. If this latter statement is true we can account for some of the results at least of oxidation taking place in the tissues. There are constant molecular changes taking place in the living tissues, these may be partially oxidation changes but where sufficient O is not present these molecular changes may result from fermentation. When H is set free O is also liberated and it acts on the oxidizable substances. Aside from the field of bacteriology to which belong what are called the organized ferments, there are the unorganized ferments or enzymes or the unformed ferments that belong properly to the field of Physiology.

Digestion consists largely of certain processes of chemical changes through which food passes in its passage through the alimentary system.

These digestive changes are effected by means of these enzymes whose action is peculiar. These are substances produced inside animals and plants although not actively endowed with life. When obtained in free solution from organic matter, they are colorless and tasteless. They can be dissolved in water and precipitated by alcohol. They are like the albumin derivatives, but do not contain sulphur. These are distinct from the living germs found in bacteria and are really dead, although they are generated in living substances. Their chemical composition is not known, although they are complex compounds. Some think that this ferment belongs to the albumin derivatives, the solutions of these ferments give the proteid reactions, but this may be due to impurity in the solution. These are usually classified according to their reactions. 1st. Proteolytic; those changing proteid into soluble peptones, proteoses or triptones. In connection with digestion we find the pepsin of the gastric juice and the tripsin of the pancreatic and intestinal juices, the former acid, the later alkaline. 2d. Amylolytic; acting on starch and changing it into a solution of sugar, or sugar and dextrin. In animal digestion we find the ptyalin of saliva, amylopsin of the pancreatic juice and a liver ferment producing sugar or glycogen 3d. Steatolytic or fat separating ferments, acting on the neutral fats and separating them into fatty acids and glycerine by the action of the pancreatic ferment called steapsin. 4th. Inversive ferments, transforming the double into the single saccharines. For example, converting the cane sugar into the dextrose, laevulose and glucose by the action of invertin in the intestinal juice, and possibly to a small extent in the salival juice. 5th. Coagulating ferments, as the fibrin ferment of blood, acting upon the proteids and producing an insoluble clot similar to this, and of the same nature as the rennin ferment of gastric juice which produces curdled milk. The fibrin ferment seems to belong to the class of albuminoids and this has led some Physiologists to suppose that all ferments belong to the same class.

This, however, is incorrect. 6th. Urea ferment, splitting up urea and converting it into carbonates of ammonia. These are found in connection with the deposits of urine. These ferments are the chief agents in the food changes that take place during the process of digestion and hence, form a most important element in considering the digestive secretions. A ferment is a substance that causes change in another substance without itself undergoing that change. This, of course, means that in causing a reaction the ferment is not itself used up. It does not mean that the enzyme continues to exist permanently or that its action is unlimited in extent or indefinite in time. The action of ferment outside of the coagulating ferments is said to be on the principle of hydrolysis. This means that the ferment acts upon the separate molecular atoms producing hydration, causing these atoms to take up one or more molecules of water. The hydrated molecule is then separated so as to form smaller separate bodies. It is not known how this hydration takes place. Some Physiologists have supposed that it was accomplished by catalysis or by the influence of contact arising from the presence of the enzyme. In addition to this it is said by others that the presence of the ferment causes vibrations in the substance among its molecules thus leading to the absorption of the fluid and the breaking up into smaller bodies. Others have said that the ferment produces a chemical reaction, without its undergoing any change itself, acting the part simply of a medium in conveying to the substance the chemical influence. This is not unknown in the field of chemistry as we find in connection with the blood, the hæmoglobin becomes oxyhæmoglobin and after delivering the O

to the tissues returning to its original form. Whatever may be the action of these ferments the presence of these ferments in the human body in connection with the juices explains largely the different processes of digestion.

SECTION IV.—1. Digestive Processes in the Mouth and Passages to the Stomach.

Digestion includes all those processes and changes through which the food passes in the alimentary canal, in order to prepare it for entering into the blood by the process of absorption. These changes are the result of several processes to which the food is subjected in its passage through the mouth, the stomach and the intestines. These processes to which the food is subjected are various. In connection with the mouth there are two, mastication and insalivation and there is deglutition in the passage to the stomach. The food is introduced into the mouth by means of the hand or some other artificial means devised for the assistance of the hands. After the introduction of the food into the mouth it is subjected to the process of decomposition accomplished by the movements of the jaws and teeth and later it is mixed with certain fluid secretions. Fluids are introduced into the mouth, passing into the pharynx and from thence to the stomach. It is by inspiration that fluids are sucked into the mouth. If the lips are immersed in the fluid in drinking, inspiration pulls out the air from the mouth, the fluid passing in under the pressure of the atmosphere. If the lips are not immersed in the fluid there is some air that passes in along with the fluid.

The movements in connection with alimentation are dependent upon the action of plain muscles. It is of importance to consider the character of the muscles as these movements depend upon the muscle. Plain muscle in the abdominal and visceral walls is composed of minute cells of varying size and shape. There is no cross striation, the cells being united to form fibers, all running in a longitudinal direction, corresponding with the cell axis. These cell plexuses form sheets of muscle which constitute the visceral walls, the coats being either longitudinal or circular. These cells are bound together by a cement substance, the cells being continuous in their protoplasm and thus affording a continuous path for the wave of contraction. These tissue walls are under the control of the motor nerves, indicating the close connection between the muscle tissue and the nerve fibers. The chief Physiological point in connection with this plain muscle tissue is the slowness of the contraction. It is subject to any kind of stimulation but the latent period is longer than usual, a slow contraction being followed by a slow relaxation. This lengthening of the periods depends upon the absence of cross striation. This however is not sufficient to account for the slowness, as other plain muscle, like the ciliary muscle, contracts more rapidly. This slowness of contraction is of great value in the alimentary canal, permitting of the slow movements of the food contents during digestion. In addition to this the passage of the wave of contraction from cell to cell provides for the contraction in either direction. This, at least, is true of the ureter, although there is no positive proof of its truth in regard to the intestines. These muscles of the intestines are always in a tonic condition, that is, a condition of normal contraction subject to an increase or decrease in the contraction taking place slowly. This characteristic contraction is called peristalsis or the contraction beginning at any point in the wall of the tubular viscus passing along the walls of the tube in the form of

a wave, each part of the tube slowly contracting and then slowly relaxing. Thus, from its entrance into the mouth until it passes out of the body the food is constantly subject to certain movements which act upon the food for the purpose of breaking it up completely, subjecting it to the digestive action. In the alimentary canal we find two layers or muscular coats, a thin longitudinal layer and a thicker circular layer separated by a connective tissue coating. The wave of contraction passing along the circular layer contracting the tube and thus pushing on the contents, the wave passing along the longitudinal layer, following the circular layer wave, helps in the forward movements of the contents and in the return of the tube to its normal size.

1. Mastication is the division of the food and its breaking up by the teeth. The food is cut by the sharp edges of the incisors and canines and ground between the rough surfaces of the molars and bicuspids. The incisors are used in biting off a part of the food, the canines in breaking it up and molars in grinding it. There is a downward and horizontal movement of the lower jaw, the former producing an upper and downward movement of the arches and the latter of grinding. The former result is produced by the alternate downward and upward movement of the lower jaw. The digastric muscle aided by the thryo-hyoid, sterno-hyoid and omo-hyoid muscles which fix the hyoid bone, open the mouth; the genio-hyoid and the mylo-hyoid pulling down the lower jaw; the temporal, masseter and internal pterygoid muscles closing it. The external pterygoids in alternation upon the two sides producing the horozontal action of the under jaw, retraction taking place by the internal pterygoid. The orbicularis oris keeps the mouth closed. The trituri tion of the food between the molars is caused by a kind of rotatory action of the lower jaw, due to the movements alternately of the external pterygoids. The food is rolled about by the tongue which pushes it between the teeth, while the contraction of the buccinator muscles prevents the accumulation of the food between the cheeks and the dental arches. The process of mastication is assisted by the mixture of the food with the fluids. If the mastication is complete the food is ready for digestive action. Complete mastication is very essential in order to prevent derangements of the digestive system. The food is rotated by the tongue backward and forward, the tongue moving around in any direction to suit the action of the food, the tongue keeping in place the food and regulating the mastication.

Mastication is a voluntary action directed by the muscles and also by the nerves. The sensory impressions relative to the position, state and readiness of the food for swallowing are carried to the brain chiefly by afferent fibers of the fifth pair of nerves and the glosso-pharyngeal in connection with the tongue. Motor influences are conveyed to the muscles concerned in mastication by the following nerves. The motor fibers of the 5th in its inferior maxillary branch to the buccinator, the anterior belly of the digastric and the masticatory muscles. The hypoglossal regulates the tongue, furnishing by the descendens noni impulses to the omo-hyoid, sterno-hyoid and sterno-thyroid and by the hypoglossal branches to the genio-hyoid and the thyro-hyoid. The facial motors supply the posterior belly of the digastric, the lip muscles and the buccinator. The reflex center is in the medulla and Pons varolii close to the muclei of the 5th, 7th hypoglossal and glosso-pharyngeal nerves.

2d. Insalivation. During mastication the food is mixed with the fluid saliva, a mixed fluid secreted by the parotid sub-maxillary and sub-lingual

glands and by the small glands of the buccal mucous membrane. The saliva is a thickish, transparent, glairy and somewhat turbid fluid with a slight sediment. In this sediment are found flat epithelium cells from the mucous of the mouth, mucous corpuscles probably leucocytes which have escaped into the secretion and spheroidal cells from the salivary glands known as the salivary corpuscles, together with protoplasmic masses with amoeboid movements. The specific gravity averages about 1003 to 1009.

The saliva is alkaline in reaction, due to the pressure of alkaline sodium phosphate, its alkalinity being about .08 per cent. It consists of water with about .5 per cent of solid matter. The solids consist of salts including lime carbonate, alkaline chlorides and the phosphates of lime and magnesia with sulphocyanide of potassium and CO_2 in combination with carbonates. Small quantities of O and N, mucin, albumin and globulin and an unorganized ferment ptyalin of the amylolytic class which has the power of converting the starch into various forms of sugar, dextrin and maltose. Ptyalin when pure by precipitation is a whitish gray powder very soluble in water. The constituents of saliva are in 1,000 parts, 994.15 of water, 2.2 of mucin, 1.4 of ptyalin and albumin, 2.2 of salts and .05 potassium sulphocyanide. Mucin is an important element, producing the viscous character of the saliva. It is formed in the gland by combination of the proteid and carbohydrate. Sulphocyanide is formed by the decomposition of proteids, being one of the products of proteid metabolism. This effect is produced more quickly where the starch is boiled, as boiling removes the celluloid envelope of the starch granules. There are other conditions favoring the ferment power of the ptyalin including a moderate temperature 70° F and the fluid in which the action is taking place being either alkaline or neutral. The various salivary secretions have been secured by the use of tubes in connection with the glands. The parotid saliva is clear and limpid, not viscous. It is slightly alkaline although the first flow is acid, and it yields but little ptyalin and traces of urea. When exposed to air it deposits lime carbonate and becomes milky. The sub-maxillary saliva is viscid on account of the mucin. It is more alkaline and contains ptyalin and sulpho-cyanide of potassium. The sublingual gland secretion is still more viscid on account of the large proportion of mucin with more salts and is very markedly alkaline.

In young children the saliva contains very little ptyalin and this in the parotid gland only. The ferment appears a few months after birth in the submaxillary saliva, after which salival secretion increases in connection with the dentition process. The chief element in saliva is ptyalin. It is found in the human saliva and also in that of lower animals. It is detected chiefly by its action upon starch. The starch is split up by a series of hydrolytic actions. It is found that sugar is formed from the starch, not directly but after passing through several stages, and that the transformation does not take place perfectly, at least when artificial experiments are made In the case of normal digestion the substances when produced are taken away so that the transformation into sugar would be more complete, indicating that maltose is the definite product of ptyalin action. The process of conversion is not known although it seems that the starch atoms take up water then dividing up to form dextrin and maltose, the dextrin again by hydration forming dextrin and maltose and so on till the process is complete. Thus dextrin appears in different forms during the process of insalivation. The action of saliva is more marked if the starch is boiled, the sugar being developed in a few minntes, whereas if the starch is uncooked it takes a much longer time, this being due to the fact that starch is bound up in cel-

lulose so the ptyalin cannot get at it, and that when boiled it has taken up water and is therefore more easily acted on. This shows the value of cooked vegetable foods as opposed to raw vegetables. From what has been said the ptyalin is found to be present in small quantities, its action being dependent upon temperature. It follows therefore, that its action is fermentative.

The function of the saliva is three-fold. 1st. To convert starch into the sugar, glucose and maltose; 2nd. To moisten and soften the food and so to assist in swallowing; 3rd. To keep the mouth moist and so to facilitate articulation. The saliva simply acts upon one substance, starch, converting it into maltose and dextrin about, one half of the starch being changed into sugar in the mouth. The conversion takes place freely at 35° but if the temperature is lower conversion is hindered as is also the case if it rises above 60° C, being entirely arrested at 70°C and at 0°C, the action being most effective at 40°C. The effect of heat seems to be in the ferment rather than in the starch substances. By boiling starch into a paste and putting into it saliva at 35°C the paste will become fluid, the sugar being found in a few minutes, the form of sugar being maltose. Saliva acts most freely in the neutral solution, its normal reaction being slightly alkaline, excessive acidity arresting its activity. Weak acidity or alkalinity diminishing its activity, strong alkaline reaction arresting its activity. The activity is most marked if the saliva is diluted with the digestive substances in the ratio of 1 to 100. If this dilution is largely increased a small quantity of sugar is still converted. Very small quantities of acid proteids will hinder and large quantities will destroy the activity of ptyalin. Hence the formation of those acid proteids retards the action of the ptyalin until it ceases to act at all. Free hydrochloric acid in small quantities .003 per cent almost entirely stops its action and if .005 per cent is present it will destroy the ptyalin. This indicates that ptyalin ceases to act on the food when it reaches the stomach.

The action of saliva upon starch is hindered by the product of salivation, sugar. Hence, the process will be arrested if the sugar is allowed to remain in the starch. If it is taken out as it is formed the process will go on. Human saliva is not very .active, its activity being directed to the moistening of food for swallowing. Food remains for such a short time in the mouth that salival action cannot be very complete, so that the chief value of the saliva is to moisten the food and by its viscidity to aid in the passage of the food through the œsophagus. In the case of soluble minerals it dissolves them. In the case of fats it has only a slight emulsifying effect. On proteids it has a moistening effect. The amount secreted by the human subject every day is estimated from 400 to 900 grams. The secretion, however, depends upon the nature of the food. In the case of any dry food where only a small quantity of water is used the secretion is large. This secretion is also increased by speaking and by the sapidity of the food.

SECTION V. Innervation Of Insalivation.

The ordinary flow of saliva is a reflex action. The lingual nerve being the afferent path and the chorda tympani the efferent path for impulses. The food substance stimulates the glosso-pharyngeal and the lingual nerves which convey impulses to a center in the medulla from which efferent impulses pass to the salivary glands.

The efferent nerve to the submaxillary is the chorda tympani. The sa-

liva is drawn from the blood under the influence of the activity of the cells, the amount of the fluid flow depending upon the necessity of the digestive system; hence, when the mouth has no food in it only sufficient saliva flow takes place to keep it moist. When the food or any substances enter the mouth the salival flow commences. The influence of the nervous system on salivary secretion and flow has been chiefly studied in connection with the sub-maxillary glands. There are connected with these glands in the human subject fibers from the facial through the chorda tympani and from the sympathetic. The chorda tympani springs from the facial nerves at the lower extremities of the Fallopian aqueduct passing through the small canal opening on the posterior wall of the tympanum, passing across the tympanum and then passing out of this canal by an opening in the interior extremity of the Glasserian fissure. It passes down along the internal surface of the internal ligament of the jaw connecting with the lingual trunk, the submaxillary ganglion and the blood vessels in connection with the tongue. This submaxillary ganglion is closely related to the lingual branch of the 5th nerve by the anterior and posterior roots, the latter carrying the fibers from the ganglion to the chorda tympani. The nerve fibers run along the duct towards the gland, nerve cells arising especially after the entrance of the hilum into the gland. The nerves enter the gland but how they are distributed in connection with the gland is as yet unknown. The chorda fibers are medulated till they enter the gland, when medulation is lost. The sympathetic also sends out fibers to join this ganglion, arising from the plexus of the facial artery. The blood vessels of the submaxillary gland are connected with the ganglion by means of a number of fine nerves, the nerve fibers reaching the gland along with the arteries of the gland. Several of these small fibers pass to the mucous membrane of the mouth. These fibers are non-medullated and may be traced to the superior cervical ganglion, thence, back to the cervical sympathetic and the spinal cord. If a tube is applied to the sub- maxillary gland a whitish turbid fluid passes out if the tongue is stimulated by some food substances or if the lingual nerve is artificially stimulated. If chemical stimulation is applied to the tongue changes may be made in these secretions, a weak solution of acid producing a clear fluid and an alkaline solution a viscous fluid. These changes are due to nervous stimulation depending upon the nerve to which the stimulus is applied. (1.) Stimulation of the sympathetics produces contraction of the arteries, a slowing of the circulation, the blood passing from the gland being of a deep dark color. The secretion is diminished, the saliva becoming thready and viscous and containing numerous corpuscles and protoplasmic lumps together with mucin. If the stimulation is long continued the saliva becomes limpid very like the chorda secretion, indicating that the chorda and sympathetic secretions are similar in their nature. Previous to the effect produced upon the secretion after the application of the stimulation there is a brief latent period from 2 to 20 seconds before the change takes place in the saliva. The fibers are the vaso-constrictor and probably act by the stimulation of the local ganglia. (2.) Stimulation of the chorda tympani at the peripheral end after its division causes the dilatation of the arteries, a quickening of the circulation, bright arterial blood passing into the veins, a copious watery secretion with free salivary corpuscles and protoplasmic masses with salts. Thus the chorda is a vaso-dilator fiber and increases the secretions. The fibers are so far as the vessels are concerned, vaso-dilators, but it is believed that some are also distributed to the secreting cells of the gland for if atropin be administered

the stimulation of the chorda tympani will still cause the dilatation of the blood vessels but no secretion of saliva. In this case the atropin paralyzes the secretory glands but not the vascular fibers of the chorda tympani. The nerve fibers in all probability dilate the blood vessels by the inhibition of the local ganglia. (3.) If the lingual nerve is cut and stimulation is applied to the central end the secretion increases very much. This secretion, however, will not increase if before stimulation the chorda tympani is also cut. (4th.) If the glosso-pharyngeal is stimulated the effect is more noticable than in the case of the chorda tympani, this being the principal afferent nerve in secretion. If the mucosa of the stomach is stimulated by the fistulous introduction of food there is a salival flow. The same result will follow stimulation of the pneumogastric or the sciatic. These are reflex in connection with the central nervous system.

From this we conclude that there is a nerve circle including sensory fibers of the lingual, a center in the brain and fibers of the chorda, producing secretion and the salival flow by reflex action. If the sympathetic, the chorda and the lingual are cut and stimulation applied and the mucous lining of the mouth, the secretion increases, indicating that the submaxillary ganglion acts as a subordinate reflex center. Normally, submaxillary secretion is limpid and the chorda activity is excited by stimulus applied to the lingual and glosso-pharyngeal nerves, or the sensory fibers of the 5th in the mouth and tongue, or the olfactory branches or the vagi branches to the stomach, all of these producing a watery secretion. In the same way flavorous substances, the masticatory action of the jaws or the presence of some solid substances in connection with the tongue produce the same flow of watery secretion. The secretory center is in the medulla close to the rise of the 7th and 9th cranials. The sympathatic fibers arise from the same point. If the lingual trunk is divided above the junction of the chorda and if the tongue is stimulated there will be no flow of the saliva. This indicates that the center must be above this point. The center in the medulla is near to the vasomotor center. If the upper part of the brain is removed, leaving intact the medulla the salival flow will continue, if there is sufficient afferent stimulation. If the medulla is destroyed the salival flow ceases. If direct stimulation is applied to the medulla the salival flow will continue, The efferent impulses pass from the center in the medulla either by the chorda tympani or by the sympathetic, although some claim that no efferimpulses pass through the sympathetic. The salival flow, therefore, depends upon efferent impulses brought the gland along the chorda tympani. By the stimulation of the chorda peripherally after division the secretion flows freely, the saliva being watery with only a few plotoplasmic substances and salivary corpuscles. The blood flows freely in the arteries, capillaries and veins, the venous blood being almost arterial in color and producing a pulsation in the veins, this being due to the fact that the blood, flows quicky and does not lose its O.

Thus, the stimulation of the chorda produces dilatation of the blood vessels in the gland and the salival flow. The difference between the chorda stimulation and the stimulation of the sympathetic is that the former gives rise to dilatation of the blood vessels and the free flow of watery saliva, while the later constricts the arteries and gives rise to a diminished flow of viscous saliva. This indicates that the blood supply is not the direct cause of the flow of secretion, although it may be connected with it in some way. In the case of the parotid gland there are two kinds of nerves, one from the central nervous system passing along the auriculo-temporal branch of the fifth and the other originating in the cervical sympathetic. The former nerves are vaso-dilator and

the latter vaso-constrictor. This center in the medulla may be stimulated not only by afferent impulses from below but also by impulses arising in the cerebrum, arising from a psychic influence connected with the thought of a savoury meal. This influence may be either accelerator or inhibitory, in the former case producing a free watery secretion in the mouth, and in the latter case, parching the mouth. Secretion in the submaxillary gland is not a process of filtration but takes place internally in the gland determining blood flow to the gland. Secretion is not arrested by the pressure becoming greater in the gland than in the arteries. Even after decapitation the secretion will continue in the gland indicating that the salivais not simply filtered through the gland from the blood but is produced in the gland cells. In confirmation of this it is claimed by some that the nerve terminals are found in the gland cell protoplasm or in the neuclei of the cells, at least they seem to be intimately connected in some way. This nervus connection with the cells has been traced in the liver. In connection with the chorda tympani two different kinds of fibers exist, secretory or accelerator or inhibitory. The use of atropin produces paralysis of the accelerator without effecting the inhibitory. If then stimulation is appliedto the chorda, no secretion takes place, though the blood vessels are dilated. Thus, thedilator fibers have not been effected at all; the secretory fibers have been effected. If the chorda is divided after the lapse of a day the Wharton duct begins to discharge the liqnid secretion called the paralytic secretion which continues to flow for several days, after which it ceases, the gland beginning towaste. If but one chorda is cnt, this watery secretion will flow from both glands. This is supposed to be due to the venosity of the blood stimulating a local center, this flow continning during the vitality of the local ganglion. During the secretry process the gland temperature is raised from 1° to 2°C producing an increase in the flow of venous blood leaving the gland as compared with the arteral blood received into it. The changes in the gland also produce certain electric influences, a change taking place between the normal gland and the gland under stimulation, resulting in a negative variation. During the resting of the gland the hilum of the gland is positive to the rest of the gland. If the chorda is stimulated the hilum becomes negative after a latent period. If the sympathetic is stimulated the hilum becomes negative to the rest of the gland. Secretion and flow are thus dependent upon three factors.

(1.) Blood supply. The secretion increasing or diminishing according to the supply of the blood. (2.) Nervous impulses. There is an increase of the secretion by the nerve activity upon the gland cells. The blood supply is under the control of the nerve fibers, one set increasing, another set decreasing supply. This nerve impulse is under the control of the local reflex center or the centers in the central nervous system. (3.) The activity of the gland c rpuscles. This means that it is due not simply to blood pressure. This is shown by the fact already referred to in reference to the stimulation of the fibers of the chord a tympani in connection with the submaxillary gland when the system is under the influence of atropin, It can also be shown by ligaturing the duct of the gland when secretion will still continue, although the pressure inside the gland is greater than that inside the blood vessels. The submaxillary ganglion appears to be a kind of secondary reflex center for the submaxillary gland If the nerves that connect the tongue with the central nervous system are divided, substances applied to the surface of the tongue cause a flow of saliva. The nerve fibers to the sublingual gland come from the lingual division of the 5th and also from the sympathetic as well as from the submaxillary ganglion. Nerve fibers passing to the parotid gland

from the glosso-pharyngeal by the otic ganglion and the inferior superficial petrosal, the immediate connection with the gland being through the auriculo-temporal. The glosso-pharyngeal through its tympanic branch passes to the internal tympanic going through the petrous ganglion. Passing along the interior wall of the tympanum, it passes out at the upper part becoming the small superficial petrosal nerve which is found in the upper part of the petrous division of the temporal bone, passing downward to the otic ganglion. The otic ganglion gets fibers from the inferior maxillary branch of the 5th, from the sympathetic and the glosso-pharyngeal through the small superficial petrosal. Thus, the nervous connection of the parotid is similar to that of the submaxillary gland.

Heidenhain has tried to explain the secretory process in the gland. In the cell we find the cell substance and also the secretion, each cell being subject to the influence of trophic fibers which produce the chemical protoplasmic changes in the cells and also of secretory fibers which are concerned in the act of secretion. In the cranial nerves, we find secretory fibers and very few trophic fibers so that the stimulation of these nerves produces a free flow of watery secretion. In the sympathetic nerves we find trophic fibers and very few secretory fibers so that the stimulation of these fibers does not produce any flow or only a slight flow of secretion, the secretion being thick. If the stimulation is long continued the secretory fibers are strongly affected so that the solid matter of the secretion is used up. A weak stimulation on the other hand, increasing the protoplasm of the secretion.

This indicates a double process taking place in the gland cell, an anabolic and a katabolic process, each of these processes being dependent upon nervous connection so that the salival flow depends very largely upon the nervous connection with the gland. As distinguished from insalivation mastication is a voluntary act under the direction of the muscular sense and the sensation. It is not, however, purely voluntary as the paralysis of the nerves controlling the tongue, takes away the influence of sensations which aid so materially the voluntary act.

SECTION VI. Deglutition.

After the process of mastication is complete by breaking up the food and mixing it thoroughly with saliva, the food is formed into a circular bolus and conveyed to the stomach by the process of deglutition which consists of a succession of complex muscular movements. This transmission takes place through the pharynx and the oesophagus. The pharynx is a muscular tube reaching from the base of the skull to the lower edge of the cricoid cartilage. The oesophagus below is continuous with it. The soft palate projects backward into it, and is an envelope passing backward from the hard palate forming the conical shaped uvula with two lateral folds, the anterior and posterior pillars of the fauces between which we find the tonsils. Between the anterior pillars is the isthmus of the faceus. In connection with the pharynx we find the three constrictor muscles and the stylo, and palato-pharyngeal muscles. The palato glossus found in connection with the anterior pillar of the fauces and the palato-pharyngeal with the posterior pillar. The levator palati elevates the soft palate. The palato glossus and pharyngealmuscles depress it. In all there are seven orifices into the pharynx, two from the nose, two eustachian tubes, the isthmus of the fauces, the laryngeal opening and the opening to the oesophagus. The oesophagus begins opposite the 6th cervical vertebra, passing through the diaphragm and entering the stomach opposite the 10th dorsal. The calibre of the oesophagus while resting, is star shaped. The upper part of

the oesophagus is striated muscle which gives rise to the quick movements of this part of the oesophagus, whereas, the lower part is untriated, the movements of this part being much slower.

Deglutition includes three periods, the passage of the bolus through the isthmus of the fauces, the passage through the pharynx and the passage through the oesophagus. After the bolus reaches the isthmus there begins the involuntary and reflex movement. There is a backward movement of the tongue and an elevation of its central part by the contraction of the stylo-glossi muscles. The tongue at the same time changes its form, sending the bolus back to the soft palate. The bolus then goes through the isthmus and the anterior pillars, contracting, and thus preventing it from returning to the mouth. It includes the passage of the food from the mouth to the stomach. It may be divided into three stages

1st. From the mouth to the isthmus of the fauces. This is the voluntary stage during which the bolus is by the movements of the tongue carried back to the fauces. When the bolus lies on the upper surface of the tongue the elevation of the tongue forces it back to the soft palate. It is voluntary in the sense that the tongue can be freely used to do this It requires, however, a moistening of the food. As soon as it passes within these fauces there commences and is rapidly completed the 2d stage, through the pharynx. This stage is spasmodic and is of the nature of a reflex action. The tongue is jerked upward and backward by the stylo-glossi muscle and thus, the food bolus is thrown into the lower part of the pharynx. The pharynx is the common tube for the food and air, and hence, more rapid movement of the food is necessary during this stage. At the same time other movements take place by which the openings leading from the pharynx except that into the oesophagus are closed, and in this way the bolus is prevented from entering them. Various steps in this process are noticeable. (a.) The muscles of mastication fix the lower jaw, pressing the arches of the teeth against each other. The pharynx is pulled up and forward by the palato-pharyngeal and the stylo-pharyngeal muscles, the constrictors and the muscles from the lower jaw to the hyoid bone. The pharynx ascends, accompanied by the ascension of the larynx. The constrictor muscles also contract from above downward, pressing the bolus against the soft edges of the palate and the tongue, carrying the bolus into the oesophagus as to prevent regurgitation of the food into the nose. The palata-glossi muscles contract and produce a narrowing of the anterior arch of the fauces. preventing the bolus from returning to the buccal cavity. Having entered the pharynx certain movements are necessary in order to prevent its passage into the nasal cavity to the trachea and to carry it into the oesophagus. (b.) The soft palate is raised by the levator palati muscles which prevent regurgitation of the food into the nose, while, by the contraction of the palato-pharyngeal muscles the two posterior pillars of the fauces are made to approach one another like the blades of a pair of scissors, leaving between them a narrow passage that is filled up by uvula. In this way there is formed a sloping shelf which cuts off the bolus from the posterior nares and the eustachian tubes.

It is a matter of dispute whether the orifices of the eustachian tubes are open or closed during deglutition. The posterior surface of the soft palate I think, is directed back toward the wall of the pharynx occupying a horizontal position and almost closing the eustachian tube. The mylo-hyoid muscles contract rapidly thus lessening considerably the buccal cavity, the bolus being quickly sent from the mouth through the pharynx and the œsophagus into the stomach, the contractions taking place in the œsophagus and pharyn-

geal walls being supplementary to drive down the remnants of the bolus. (c.) As the tongue is jerked upwards and backwards the hyoid bone with the pharynx and larynx is carried upward and forward. Hence the base of the tongue presses the epiglottis down over the superior aperture of the larynx. The closure is completed by the constriction of the muscular fibers connected with the epiglottis. At the same time the rima glottidis is closed, the arytenoid cartileges and the true vocal cords being brought close together, the cushion of the epiglottis fitting in between the cords. The general view is that the epiglottis presses down on the laryngeal opening, closing it and protecting the respiratory passages. If the epiglottis is taken out normal swallowing continues. According to some recent cases the epiglottis becomes erect in swallowing although this is not accepted as correct. By these means the orifices leading from the pharynx are closed with the exception of that into the œsophagus. The œsophagus and the lower part of the pharynx are somewhat raised to meet the descending bolus by the contraction of the stylo-pharyngeal and palato-pharyngeal muscles forcing the food downward and thus preparing for the 3rd stage. During this stage, therefore, the buccal cavity is closed by the tongue pressing upon the soft palate and by the constriction of the muscles of the anterior pillars of the fauces. The nasal cavity orifices are closed by the raising of the soft palate, of the uvula and the constriction of the muscles of the posterior pillars of the fauces. The tracheal opening is closed by the constriction of the vocal cords, the elevation of the larynx and the lowering of the epiglottis over the larynx. In this way a clear and well marked passage is cleared for the food through the pharynx.

3d. In the oesophagus, this is the involuntary stage. The constrictors of the pharynx close over the food which enters the oesophagus along which it is carried by peristaltic contraction. When the food enters the oesophagus the pharynx falls downward, the openings of the mouth, the nasal cavity and the glottis being opened and the fragments of food being carried down by a succession of oesophagal contractions. The oesophagal movements are undulatory; and hence, they are called peristaltic. The circular contraction originating in the pharynx passes into the oesophagus, being first communicated to the transverse coats of the oesophagus and then assisted by the contraction of the longitudinal coats, the movements being always directed downward. The muscles of the oesophagus are found to contain striated fibers in the upper part, and unstriated fibers in the lower part, peristaltic action being the same in both except that in the striated fibers it travels much more rapidly. These peristaltic movements may be carried out by the muscles without any assistance from the nerve fibers, terminating in the muscles and apart from any stimulation from the central nervous system, as these can be seen in the organs when removed the body.

But in the living body the connections are so close with the nervous system as to make the connection of nerves and muscles inseparable in the production of peristaltic action. The contractions do not originate and are not carried out by the walls of the tube alone and thus transmitted from segment to segment in the tube. The efferent impulses pass from the medulla to the different regions of the tract. Hence, if a part of the œsphagus is excited the contraction will commence and go down the oesophagus to the cut portion and will proceed to go down the lower part, crossing the gap, indicating that nervous stimulation passes to the oesophagus in all its parts from the central nervous system. Persstaltic movements of the lower portion of the oesophagus can be aroused by irritating the pharnyx. In the production of these peristaltic movements of the oesophagus we find the pharyngeal afferent nerves, the

superior laryngeal, the pharyngeal branches of the pheumogastric, the branches of the 5th and the branches of the glosso-pharyngeal. The center of peristaltic action is in the medulla being a portion of the deglutition center, the efferent impulses pass from the center along the pneumogastric, passing by the recurrent laryngeal to the upper part of the pharynx and through the pneumogastric laryngeal plexus to the lower part. If the vagus trunk is divided deglutition in the last stage through the oesophagus is difficult. If the If the pheripheral end of the cut trunk is stimulated, then the peristaltic contractions are noticeable. Where the œsophagus unites with the stomach at the cardiac orifice in the last part of the oesophagus the circular fibers continue in a tonic contracted state, especially when the stomach is filled. This contraction of the lower end of the esophagus acts as a closure sphincter, preventing the regurgitation of the food from the stomach. When the food reaches this point the center which controls this part is inhibited, so as to dilate the orifices and permit the passage of the food into the stomach which comes with sufficient force to press through the small opening, producing a sound over the upper region of the abdomen. These movements of the oesophagal walls are very much like those found in the stomach and intestines. The muscular coating of the alimentary canal consist of two layers, the external thin layer arranged longitudinally and an interior thick layer arranged transversely with a layer of connective tissue in the middle. When constriction takes place in the transverse layer the contraction is transmitted downward, causing contractions of the circular layers. This causes the contraction of the tube pushing forward the contents. In the case of the longitudinal layer a contraction of any portion of the tube helps forward the contents by drawing the tube over the contents immediately above. These contraction movements are transmitted all along the walls of the tube. The transverse and longitudinal contractions are supposed to take place at different times and not simultaneously, because similtaneous contractions would tend to neutralize each other. It is supposed that longitudinal contraction takes place first and accompanies transverse relaxation and vice versa, the thick coat of the transverse representing the stronger force, the thinner longitudinal coat assisting the movements forward. These conjoint movements produce a writhing and twisting in the walls along the tubes of the intestines, which is called peristaltic action. All these movements in deglutition are induced, if not produced, by the stimulation arising from the food or liquid coming into contact with the tongue and fauces. These movements are aided by the insalivation of the food and the closure of the mouth, as it is very difficult to swallow any substance with the mouth open.

These movements originate from stimulation by the food or drink brought into contact with the posterior portions of the tongue and the anterior portions of the fauces. This is greatly assisted by insalivation of the food, as dry food is almost impossible to swallow. The same difficulty in swallowing is experienced when the mouth is kept open. By experiments it has been found that deglutition lasts about 6 seconds; about 3 seconds representing the movements of the lower pharynx and oesophagus and three seconds the upper pharynx. If the respiratory passages are not closed the food passes into the larynx, producing excitation, resulting in choking sensations. This irritation produces expiratory movements, followed by a cough which drives out the foreign particles.

According to Kronecker and Meltzer soft food is forced through the pharynx and the oesophagus by the quick and powerful contraction of the mylo-hyoid muscles. When the food lies on the surface of the tongue, by the pressure of the tongue against the palate, it is forced back to the back part of

the mouth, and prevented from coming forward. At this point under the contraction of the mylo-hyoids the food is forced through the pharynx and oesophagus. The movements of the hyo-glossi muscles move the tongue back and downward, pressing down the epiglottis over the larynx and pressing the food downward. The food bolus, according to their conclusion, reaches the opening into the stomach in 1-10 of a second. The action of the pharyngeal constrictors and the oesophagus peristalsis does not assist deglutition but takes place after the swallowing of the food, the object of which is to clear down the fragments, and if the food bolus is detained to push it down more slowly through the pharynx and the oesophagus. According to these Physiologists the food bolus when it has passed to the lower end of the oesophagus stops, on account of the tonic contraction of the sphincter until the peristalsis reaches that point so as to relax the sphincter and thus permit the passage of the food into the stomach. The peristaltic wave reaches that point about 6 seconds after the entrance of the food into the mouth. Instead of there being two regions in the oesophagus as we find in the old theory, according to these investigations there are three regions, the upper, middle and lower, so that there are three contractions in the peristaltic movements. These three contractions together with the pharyngeal constrictors and the mylo-hyoid muscles are the five segmentary contractions producing deglutition in normal circumstances. This represents a new and simpler theory of the deglutition which as yet has not been fully confirmed. If confirmed it will simplify very much the physiology of deglutition.

The Nervous Arrangement of Deglutition.

Deglutition as a whole represents a reflex action complex in character. It is impossible without some stimulation of the mucous coat of the fauces. The first stage represents a voluntary action, the second stage is said to be partly voluntary and partly reflex. The movements, however, may take place involuntarily and during unconsciousness. In the last stage it is purely involuntary, the will having nothing to do with the action and the movements concerned. It is a complicated reflex action, therefore, involving many muscles, all these muscles co-operating to produce definite results, the connections and the results being very definite. The nervous connections associated with the act of deglutition are, 1st, afferent sensory fibers carrying impulses to the centers; the glosso-pharyngeal in connection with the tongue and the pharynx, the branches of the 5th pair of cranial nerves from the palate and the tongue and the pharyngeal branch of the superior laryngeal portion of the pneumogastric from the upper laryngeal orifice. 2d. The center of reflex action lies in the medulla and the Pons Varolii. If an animal's brain is removed leaving the medulla, deglutition can be induced by stimulating the fauces, even if the animal is unconscious. If the medulla is removed deglutition is impossible. Various centers have been localized in the nucleus of the 7th, the pneumogastric and the glosso-pharyngeal, the 5th and the hypo-glossal, all those being closely grouped together. The deglutition center is higher than the center of respiration, so that when the lower part of the medulla is injured the deglutition process may go on unimpaired. Possibly this center like others, cannot be confined to a small local area but covers the region representing the nuclei of the origin of efferent fibers to the muscles of deglutition. 3d. The efferent motor nerves carrying impulses to the muscles of deglutition are the hypoglossal to the thyro-hyoid, genio-hyoid, hyo- and stylo-glossi muscles and the intrinsic muscles of the tongue, the glosso-pharyngeal and the

pharyngeal plexus formed from the pharyngeal branch of the pneumogastric and the sympathetic to the constrictor muscles of the fauces and pharynx, the palato-glossal and the palato-pharyngeal; the 5th pair of nerves by the mylo-hyoid branch of the inferior maxillary to the anterior belly of the digastric and the mylo-hyoid muscles; the 7th or facial to the posterior belly of the digastric to the stylo-hyoid muscles, the glosso-pharyngeal to the stylo-pharyngeal muscle and the laryngeal branches of the vagus to the laryngeal muscles.

SECTION VII.—2.—Digestive Processes That Take Place in the Stomach.

The stomach is a special organ of digestion. The stomach has three coatings, the mucous, muscular and serous layers. The mucous lining consists of epithelium, tunica propria with tubular glands, muscularis mucosæ, and the sub-mucous tissue. The epithelium consists of the columnar cells secreting mucus, the mucin being found contained within the protoplasm at the upper surfaces. There are two kinds of glands found in connection with the stomach, the cardiac and pyloric glands, simple glands opening into the surfaces of the mucous membrane. In the cardiac glands we find two kinds of cells, the principal or the hidden cell and the parietal or oxyntic cells; the latter being largely marginal cells found in the body and neck of the gland and the principal cells in the tube. It is in the marginal cells where the hydrochloric acid of the gastric juice is secreted. The pyloric glands have the columnar cells. During fasting from food the fundic cells are shrunken. After taking food the cell enlarges; this enlargement being removed at a later stage of digestion. In the pyloric gland during digestion the cells become darker and more granular. The muscular coat consists of two layers of smooth muscle fibers and the serous coat consists of peritoneal membrane. The three coatings, the longitudinal circular and the oblique represent the action of the stomach. The circular coat lies between the other two and is more important. At the end of the fundus the circular coats are thin but increase in thickness towards the pyloric end, forming a very massive structure of great importance in the stomach movements. The vascular mechanism of the stomach consists of minute arteries distributed on the serous coating entering the muscular layers and then penetrating the submucous coat in a dense capillary mesh work from which delicate vessels pass to the tunica propria forming plexuses at the glandular base. Minute capillaries pass from these plexuses around the gland orifices. It is from these that the small veins arise, passing to a venous plexus in the tunica propria.

The lymphatic arrangements of the stomach are found in connection with minute tubules passing out between the glands, uniting with the lacteal plexus at the base of the glands, these passing to a larger system in the submucous coat. Here arise lymph vessels with valves passing to the muscular coatings, the muscular tissue being freely supplied with lymphatics. The lymph vessels which have collected the lymph then pass along the serous coating to the mesentery passing between the coatings to the mesenteric glands. The nervous connection to the stomach is furnished by the branches of the pneumogastric anc of the sympathetics from the solar plexus. The sympathetic fibers arise from the spinal cord, psssing through the thoracic ganglia to the splanchnics and the solar plexus. These reach the stomach as non-medullated fibers. The vagi as they reach the stomach are also non-medullated, the fibers of the vagi being motor. Numerous fibers, chiefly non medullated constitute plexuses underneath the serous coating

from which the fibers pass into the outer muscular layer forming plexuses between the two muscular layers. From these plexuses great numbers of fine fibers pass into the submucous coat again forming plexuses from which fibers pass to the glands. Thus the vascular lymphatic and nervous connection is very complete. When the food reaches the stomach it is subject to the following influences:

1st. A temperature of about 104° F

2nd. Certain movements and compression. These movements take place by rythmic contractions of the muscular coatings, the object being to bring food directly into contact with the juices and when digested expel it into the duodenum.

3rd. The action of the gastric juice secreted by the glands in the mucous membrane.

4th. Absorption takes place in the stomach. The temperature will be considered in connection with the gastric juice and absorption after we have finished digestion. 1st. The movements: Stomachic movements have two objects. 1st. In order to subject the stomach contents to the influence of the gastric juice and 2nd, to throw the food when partially digested into the first portion of the lower intestines. Hence a distinction has been drawn between two stages in these movements called the churning and propelling movements. When the stomach is empty it is curved from above downwards, all the muscles being in a tonic condition of contraction. The stomach is lessened in size by contraction, the cavity being almost closed up, the mucous membrane being unfolded in connection with the circular fibers. When food reaches the stomach and when it is filled the stomach begins to relax except at the pyloric orifice, the cardiac orifice opening as food enters. The stomach rotates on its long axis so that the greatest curvature is carried forward, the anterior surface is carried upward and the posterior surface downward. Thus the stomach extends in the direction where there is freer action towards the frontal abdominal walls. The muscular fibers of the stomach contract the on food and cause it to circulate, the current passing from the cardiac orifice along the great curvature and back again by the lesser curvature, while at the same time other currents carry the food which is in contact with the mucous membrane of the peripheral portion to the deeper parts of the stomach and vice versa. These actions give rise to rotatory movements of the contents of thestomach, the rotations taking place successively at short intervals and last for a few minutes. These movements are of the nature of peristaltic contractions producing the churning movements. The contact of the food with the mucous membrane of the stomach produces a mechanical stimulation which is strengthened by the chemical action of the gastric juice. These movements result in complete mixing of the food with the fluids, the movements becoming more marked as the digestion proceeds. In this way the food is thoroughly churned and its complete admixture with the gastric juice is secured. The contraction of the gastric muscular fibers is at first slight and becomes increasingly active as digestion proceeds, that is as the stomach gradually empties. While digestion is going on the pyloric orifice is closed by the sphincter. As digestion proceeds there are propulsive movements occuring at intervals. These consist of contractions of the circular fibers beginning at the antrum of the pylorus, passing downward and propelling the food downward. From time to time the pyloric sphincter relaxes, due to the inhibition of the pyloric contraction, a portion of the food passes from the stomach into the small intestine (duodenum). This movement is sudden,

in the form of a very quick contraction, being actively marked at the pylorus.

The action of the sphincter seems to depend on the contents of the stomach. for undigested parts of the food do not pass through the pylorus but are driven back again into the stomach. The churning and propulsive movements usually drive the fluid part of the contents in the form of chyme into the duodenum, the more solid parts remaining in the stomach for the further action of the gastric juice. The food substance is gradually conveyed to the duodenum, the indigestible elements being the last to pass from the stomach. Some indigestible elements do not leave the stomach, causing the disagreeable feeling in the stomach. The presence of the food does not cause the movements as when the stomach is fullest the movements are at the lowest. It is rather acidity that produces the movements by stimulation. These movements take place at intervals of 15 minutes until the food is all digested and emptied into the small intestine. The nervous mechanism of the stomach is supplied by the pneumogastric and the splanchnic nerves. If the sympathetic is stimulated there do not result any movements. If, on the other hand, the pneumogastric is stimulated, active movements occur in the cardiac portion, particularly if the stomach is dilated. If the sympathetic or pneumogastrics be divided these movements are not suspended, indicating that the ganglia which are found in the plexuses of the abdominal walls act as centers of activity even after separation from the central nervous system. If the splanchnics are stimulated these contractions cease, their action being inhibitory, stimulation producing dilatation of the contracted stomach and relaxation of the sphincters, the vagi nerves in connection with the sphincter causing the contraction. Thus, the movements in the stomach walls are due to local influences arising from impulses sent out from the ganglionic centers. Impulses conveyed along the pneumogastric excite these movements to become more vigorous whereas, impulses conveyed along the splanchnic sympathetics exercise the inhibitory force. Recent experiments indicate that there are also inhibitory fibers in the vagus and the sciatic nerves. The stimulation of the central ends of these nerves inhibiting the tonus of the stomach. These movements under impulses are regulative as we have seen that the stomach movements are almost purely muscular.

If the stomach is subjected to a shock produced either by striking with a flat instrument, or by the applications of induction shocks, there will arise certain contractile movements. These movements as undulations being transmitted along the abdominal walls. The stomach movements thus do not depend upon the connection of the stomach with the central nervous system. If the extrinsic nerves are divided even, after the removal of the stomach from the body, these movements continue, provided the temperature and moisture are sustained. This indicates that the stomach acts automatically, that is, independently of the nervous stimulation. The movements are like the heart movements, that is, muscular. The antrum pylori seems to be the chief cause of the movements of the stomach, originating both the pyloric movements that drive the food contents from the stomach and the movements that keep the contents in motion in the stomach. According to some, there are no movements of the fundic end, the fundus remaining in a normal tonic condition. According to others the contractions begin at the cardiac end and continue toward the pyloric end. This latter seems to be the more correct opinion. The movements begin at the cardiac end, which at first are quite feeble caused, by the contraction of the

circular fibers, the wave thus originated passing towards the pyloric end with increasing force. When the wave reaches the parietal region it comes to a stop. Following this there is a contraction of the entire pyloric end which drives the liquid part of the contents through the fundus, an anti-peristaltic wave, being originated that returns the larger solid elements to the stomach again. There are thus two characteristic forms of movements. (1) The weak peristalsis of the fundus, pushing the contents toward the antrum and (2d,) the strong contraction of the sphincter pylori, accompanied by a strong stimulation of the entire antrum, both circular and longitudinal. These combined phases of movements would keep up a constant motion of the contents of the stomach toward the pyloric end. From this it will be seen that the fundic portion of the stomach is largely a reservoir for holding the contents, while the pylorus is the part of the stomach that through its muscles produces the stomach movements. The two parts of the stomach, therefore, have different and independent functions. This is of great advantage to the digestive process, as the large cavity represented by the fundus can hold the food, while gradually the food subjected to digestion, is sent down to the intestine through the pylorus. It not only assists digestion but protects the intestines from congestion so that the digestive process is completed.

VOMITING. This is intimately connected with these digestive movements that we have just explained, and hence, may conveniently be discussed in this part of Physiology. The act of vomiting is due to the direct or indirect stimulation of the center situated in the medulla. It may be produced, 1st. By the stimulation of afferent nerves of the gastric mucous membrane. For example, the introduction into the stomach of some irritant such as mustard, sulphate of copper, bile and undigested food. These substances either act directly upon the mucosa of the stomach or after absorption into the blood by influencing the reflex centers connected with the stomach movements. 2d. By substances introduced into the blood and acting upon it or else absorbed into the blood through the skin. For example, the injection of tarter emetic into the blood. 3d. Irritations of other organs affecting the stomach reflexly through the centers of reflex action. For example, tumors in the abdomen, certain conditions of pregnancy, gall stones, calculi, etc. 4th. Impressions reaching this center from the higher centers depending upon the psychic action, for example, arising from feelings, emotions, tastes, odors, etc. Sea sickness falls under this head, arising not from the food in the stomach but from a disturbance of the feeling of equilibrium in the bodily system, particularly in the stomach. 5th. Vomiting may arise from the reflex action produced by inflammations. For example, in acute meningitis. From the center in the medulla when it is stimulated a series of complicated efferent impulses pass. Some of these travel along the vagi aad cause contraction of the walls of the stomach and the abdominal muscles. There are several characteristic stages of vomiting in the conscious individual.

1st. Nausea. Vomiting is usually preceded by a nauseous feeling accompanied by a salival flow and the swallowing of some air which assists in the opening of the cardiac orifice to prepare for the discharge of the contents. 2d. Accompanying this is a deep inspiration by which the diaphragm is pushed down, the lungs being full of air, the diaphragm forming, thus, a solid base against which the stomach can be compressed. Accompanying this there is a contraction of the lower ribs, and the air does not enter the lungs as the glottis is closed, some air passing into the pharynx

and to the stomach. Sometimes this compression causes the ejection of a quantity of gas. Associated with this is sometimes a retching accompanied with a deep inspiration. 3d. Immediately thereafter the fibers of the oesophagus contract longitudinally and are shortened, the opening of the cardiac orifice which is close under the diaphragm then takes place, in connection with the inhibition of the sphincter and the constriction of those fibers ranging from the oesophagus to the stomach. (4) The abdominal muscles and the gastric walls contract, the contents of the stomach being forced into the oesophagus along which they are carried into the pharynx by antiperistaltic action and ejected through the mouth, the openings into the larynx and the nasal cavity being closed as in deglutition, although sometimes they remain open and matters are forced out through the nasal opening. When vomiting becomes violent the stomach is violently pressed against the diaphragm and the vertebrae, the abdominal muscles contracting powerfully, following this vomiting there is a deep expiration resulting in abdominal contraction, all the strength of the muscles being exhausted in the expulsion of the contents of the stomach. The involves a compression from the outside of the stomach. There are two marked actions in vomiting: 1st, the distension of the cardiac opening and 2d, the compression of the walls of the abdomen, both of these being necessary in order that the action may be affected. Sometimes the former takes place as poisoning by curare, in which case there is simply an internal stomach pressure, resulting in the emission of the gas. What is commonly called water-brash or heartburn is probably due to this internal movement of the abdomen. Eructation of wind consists of a sudden forcing of gas out of the stomach producing a sound which is very characteristic in the upper part of the oesophagus. During vomiting the pyloric orifice is closed so that the contents do not pass into the duodenum. If the gall bladder is well filled there is a flow of bile to the duodenum along with the vomiting. In some cases this bile passes to the stomach, as in the case of bilious vomiting. The nervous arrangements of vomiting are obscure. The center is in the medulla in connection with the deep origin of the glosso-pharyngeal and pneumogastric nerves. There is really no special center. The reflex, however, takes place in connection with the medulla. But the respiratory muscles are those engaged in the act of vomiting. Vomiting consists of spasmodic actions of the expiratory and the inspiratory muscles. Some have concluded that the center is the same as that of respiration. This however lacks confirmation. In addition to this there is evidence that if the medulla is divided so as to suspend vomiting, respiration continues. Efferent impulses causing the deep expiration must come from the respiratory center. The distension of the cardiac opening is produced by stimulation passing along the pneumogastrics, because if these are divided vomiting is prevented or rendered almost impossible through lack of dilatation of the orifice. The internal stomachic movements and the movements of the oesophagus are carried out under the influence of the glosso-pharyngeal and the sympathetic nerves. The salival flow in connection with the nausea arises from impulses passing along the chorda tympani. These various mechanisms are brought into activity by the stimulation of different centers, impulses being passed from one center to another, thus interfering with the rhythm of the movements in the stomach. Vomiting is, therefore, a reflex action, the impulses usually passing along the splanchnic and pneumogastric nerves. This does not prevent direct action upon the centers as in abnormal conditions of the medulla resulting in cerebral vomiting and in some cases of poisoning as

well as under the influences arising from the higher centers that depend upon emotions. Irritations in vomiting may give rise to stomach movements, the movements of the abdominal muscles and the respiratory movements. Those interferences with normal movements take place by the radiation of impulses from center to center. Vomiting is thus a reflex action resulting either from sensory stimulation or from injury to the nervous system. Injuries of the brain cause cerebral vomiting. The most regular cause, however, is the stimulation of the mucous membrane of the stomach the afferent path being along the pneumogastric and the efferent path being found in the motor fibers of the vagus, phrenics and spinal nerves.

SECTION VIII. (2) The Gastric Juice.

When food reaches the stomach it is brought into contact with the gastric secretion which begins as soon as the food enters the stomach, The gastric juice is easily obtainable for experimental purposes but it is difficult to determine the normal characteristics of the fluid in the stomach. By causing an animal to swallow a sponge the sponge can be withdrawn and the juice squeezed out. In the famous case of St. Martin, who by a shot was wounded in the abdomen, there was a fistulous opening existing in the abdomen wall and the stomach wall so that the contents of the stomach could be easily examined. The most easy method is by means of the gastric fistula through the abdominal walls introduced into the stomach. Investigations have been made in connection with the production of artificial gastric juice secured by the use of alcohol in connection with the mucous membrane of the stomach, afterwards using glycerine and hydrochloric acid. These, however, only represent in a general way the gastric juice as normally it is complicated by mixture with the food, fluids, etc. When it is secured in purity it is a thin, clear, colorless fluid with a sour odor and taste, the reaction being distinctly acid, arising from free hydrochloric acid to the extent of about 1-10 to 2-10 per cent. Its specific gravity in the human subject is about 1.001 to 1.003. On microscopic examination it does not present any well marked characteristics. In the human gastric juice the amount of solid matter is very small, about .5. Of this solid matter the greater proportion is found to be salts, especially the chlorides about .2 per cent, and small quantities of phosphates with small traces of iron. There is always a free acid, hydrochloric acid, together with lactic acid and other acids which are secondary, the result of fermentation changes in the food. There is a small quantity of albumin, some mucin and a ferment pepsin which can be extracted from the gastric mucous membrane by glycerine and which when dried appears as a grayish white powder, slightly soluble in water. This pepsin in combination with hydrochloric acid has the power of converting ordinary proteid substances into peptones which differ from the ordinary proteid snbstances as follows:

1st. Their solutions are not coagulated by heat or by alcohol. When boiled no coagulation takes place but the digestive character is destroyed. 2d. They have the power of passing with considerable ease through animal membranes. 3d. They are easily dissolved in water. 4th. Mineral acids, acetic acid and such other acids do not precipitate the solution. 5th. Such acids as tannic acid, corrosive sublimate, do cause precipitation. 6th. In cold they yield a purple red color when added to an alkaline solution of hydrated capric acid. 7th. In dry powder dried at 105° C it is of a bright yellow color, the powder freely absorbing water from the air. Besides pepsin the gastric juice contains another ferment which, as it has the power of

curdling milk, is called the renin ferment changing milk sugar into lactic acid. The gastric juice freely dissolves coagulated proteids which seem to be almost insoluble. There are supposed to be several kinds of peptones in connection with the gastric juice. These all differ from albumose in the fact that peptone is diffusable, whereas, albumose is not, and a peptone cannot be precipitated by sulphate ammonium like albumose. The gastric juice changes the less soluble proteid into a soluble form being either converted into peptone which is the most soluble form of the proteids or else being left in the less soluble form of para-peptone. Gastric juice resists putrefaction even after being kept for months. It does not become putrid and it does not lose its digestive or acid character. This makes the juice antiseptic. This conversion of proteids into the peptones is facilitated. 1st. By a medium temperature from 35 to 40°C. 2d. By certain mevements such as we find in connection with the stomach's constant movements, favoring digestion. The presence of acid below or beyond the normal percentage, .2 per cent of hydrochloric acid, retards the action of the juice; the making of the juice alkaline and a temperature below 50°C or above 60°C and the presence of concentrated digestive product retards, or arrest the changes in connection with gastric juice. The blood is conveyed to the fundus and the pyloric glands the fluid being poured from the capillaries so as to suffuse the membrane, the plasmic fluid being secreted in the cells of the glands as the elements out of whicn the juice is formed. In the glands of the plyorus the pepsin is formed. When the stomach is inactive, the marginal glandular cells decrease in number. When food is introduced into the stomach the principal cells decrease, producing large numbers of marginal cells in which the hydrochloric acid is formed, whereas the pepsin if found secreted in the principal cells in connection with the fundus and pyloric glands.

Heidenhain separated a part of the fundus in the dog from the rest of the stomach without interfering with the vascular connections. This part of the fundus he formed into a sac by stitching; he formed in the same way a pyloric sac. The fundic sac secreted the fluid containing pepsin and hydrocloric acid, while the pyloric sac contained a viscous alkaline secretion containing pepsin. He concluded that as marginal cells are found only in the fundus they secrete hydrochloric acid and as the principal cells are found both in the fundus and the pylorus he concluded that they secreted pepsin. The hydrochloric acid is formed out of the blood. It is difficult how to explain how the alkaline blood produces free hydrocloric acid. It is supposed that lactic acid is first formed by means of the ferment, the acid setting free chlorine from the sodium chloride, the chlorine being combined with the hydrogen to form hydrochloric acid. CO_2 is the only acid in the blood and it is said that chlorides are decomposed by its action. This, however, is impossible. Others suppose it due to certain currents passing through the mucous membrane producing reaction in the carbonate of sodium and the sodium chloride of the blood. At one time it was supposed to be due to the lactic acid alone.

Schmidt then showed that if the chlorides were precipitated by silver nitrate more chlorine would be found than could be held in combination with the gastric bases. The lactic acid, however, may and often does exist in the juices. The lactic acid is explained as arising from fermentation of the carbohydrates. The gastric juice is the only secretion containing a free acid. Various attempts have been made by injecting coloring reactions into the blood to locate the secretion of the acid, but so far without success

unless to the extent of proving that the acid is formed in the mucous membrane. As no free acid exists in the blood it must be formed in connection with the cells. It is supposed by some that the hydrochloric acid is held in combination with some of the proteids of the secretion, the result being that the acid is not so easily distilled or dyalized as in its free condition. In proof of this it is stated that the para-peptones and the peptones very freely combine with the acid. A more probable explanation is that it arises in the molecular dissolution and of the chlorides accomplished by the protoplasmic action of CO_2. The liberated base in this case is excreted by means of the kidneys, the urine acidity being inversely in proportion to that of the stomach. In the principal cells there is found certain matter which, under the influence of hydrochloric acid produces pepsin, the albumen being converted into peptones. Thus the matter inside the cells contains substances which can produce pepsin, and hence this internal substance is called pepsinogen. This pepsinogen is supposed to be in union with a proteid and it is supposed that the union is broken up by the use of acid. If both pepsin and pepsinogen are found in the same fluid, a one per cent solution of sodium carbonate will destroy more pepsin than pepsinogen and CO_2 will destroy more pepsinogen than pepsin. If all the pepsin is removed from the stomach by a glycerin solution then more pepsin can be obtained by the hydrochloric acid or sodium chloride solutions.

The pepsin found in the gastric juice varies according to the stages of the digestive process, being smallest about the second hour and greatest about the fifth hour, after which it falls to about the normal. There is no pepsin found in the mucus of the foetal stomach during foetal life, although it is said that just before birth the stomach assumes the digestive powers. The gastric juice in digestion seems to act as a ferment, this ferment being the pepsin. It is not inself a proteid; it differs from ptyalin, the salival ferment in this, that pepsin has a close affinity for acid, whereas, ptyalin is most active in a neutral solution. In the case of pepsin united with hydrochloric acid we have a compound pepto-hydrochloric. Pepsin is a proteolytic enzyme which acts only in an acid fluid. Hence, the digestion in the stomach is the result of the union of pepsin and hydrochloric acid. A low temperature hinders its action and may arrest its activity; the higher temperature increases its action. The normal temperature is about 35° to 40°C. If the temperature is raised to 70° or 80°C it destroys the pepsin. The amount of pepsin in the gastric fluid varies from .2 to 1.5 per cent. Pepsin is freely given up to glycerine. If the mucous membrane of the stomach is divided into small pieces and steeped in alcohol for a day, then removed from the alcohol and put into a strong glycerine solution in which it is allowed to remain from 10 to 21 days, after which the fluid is strained, this gives us the glycerine extract of the mucous membrane which is found to be very peptic. It may also be obtained by pouring a 5 per cent solution of phosphoric acid and later some lime water on the mucous membrane. Phosphate of lime precipitates pepsin. If the precipitation is collected and washed with water then dissolved in a .5 per cent hydrochloric acid solution, a solution of cholesterin, alcohol and ether produces a precipitate of cholesterin and pepsin. By the use of ether the cholesterin is dissolved and there is left a fluid solution of pepsin. The gastric juice on analysis yields in 1,000 parts, according to Schmidt 994.4 parts of water; 3.19 of pepsin and other organic matter; 1.46 sodium chloride; .55 potassium chloride; .06 calcium chloride; .2 acid and .12 phosphate of lime, magnesia and iron. Artificial digestion may be carried on at a temperature of 35° or 40°C. Be-

Peptones ready for absorption
Proteins — not until acted on by p

low this the process becomes slow and at 4°C it is arrested. In addition to the pepsin there is usually present the rennin ferment and the lactic acid ferment which converts sugar into lactic acid. Syntonin is formed during the first part of the process. By the use of an alkali this may be precipitated, a part of the proteid substance being left in the neutral fluid, this substance being peptone. In addition to this there is formed the parapeptone, an albuminous substance soluble in water and may be precipitated by nitric acid. If heat is applied to the precipitate it dissolves but it may be precipitated again by cold. In the first stage of the digestive process a large proportion of the para-peptone or pro-peptone is found and a small quantity of peptone. As the digestive process goes on, the peptone increases and the para-peptone decreases until at the close of the digestive process very small traces of the para-peptones are left with a large quantity of peptone. In the process of digestion a number of intermediate substances are formed, called by Halliburton, proteoses, these different substances representing the different stages in the development of peptones, all of them being albumose in character. All these albumoses are precipitated by ammonium sulphate. Kuhne says that the proteids divide up into anti-peptone and hemi-peptone bodies; the anti-peptone being divided later under the action of tripsin in the pancreatic juice into leucin and tryosin. To discover the presence of pepsin in a fluid, acetic acid must be first added, then the substances must be saturated with ammonium sulphate and then filtered. This is then treated with strong hydroxide and a very small quantity of cupric sulphate dilution. There will be a red colored reaction if there is peptone present and a blue colored reaction if there is no peptone present. When the proteid is acted on, according to Kuhne it is converted into the syntonin which is the characteristic peptone of the acid albumin. If the liquid is neutralized syntonin will be formed chiefly due to the presence of hydrochloric acid. The syntonin is then hydrated under the pepsin influence the dissolution forming the proteoses, proto- and heteso proteoses. Each of these substances changes again under the influence of hydration, forming secondary protoeses, these secondary proteoses being again changed in the formation of peptones. Here the digestive action of the gastric juice ceases, although the peptones may be still farther changed under the influence of the tripsin ferment. All of the stages after the development of syntonin are hydrolytic stages according to which dissolution takes place of the proteids into smaller bodies, these representing the proteoses and peptones. Formerly all the products of digestion following the syntonin were called peptones, but now, under the influence of Kuhne's experiments the peptones are taken to represent the final products of the digestive action, the test of the peptone being the absence of precipitation under the influence of ammonium sulphate. The peptones are albuminous. It is supposed that they are formed by hydration an atom of albumin being united with a drop of water. This is proved by introducing acetic acid into the pepsin and thus dehydrating the molecules by removing the water and thus converting the peptones into the albumin. By the action of a .4 per cent solution of hydrochloric acid at a temperature of from 40° to 60°C peptones may be produced. If albuminous substances are boiled for a long time peptones will also be formed. This production of peptone is slow, whereas, by the action of pepsin the formation of peptone is rapid. The hydrochloric acid may be replaced by lactic acid, phosphoric acid, oxalic acid and succinic acid. The digestive process is influenced, first by gastric secretion which goes on during the entire digestive process, the food being

mixed with fluid in connection with the pepsin and hydrochloric acid so as to produce the proper mixture and dilution of the food. 2d. When the peptones are formed during digestion they are absorbed into the blood through the blood vessels together with water, the remnants being passed into the small intestine. 3d. The stomach movements facilitate digestion by introducing the food contents into the different parts of the mucous membrane of the stomach and thus bringing them into contact with the gastric juice. 4th. Albumin will be readily transformed into peptone at 40°C, being stopped below 5° and above 60°C. 5th. The pepsin is quickly destroyed by the action of alkalies, its action is also hindered by the metallic salts, sulphurous and arsenious acids, large quantities of cold water and the presence of a large quantity of the peptone itself. A small quantity of salt favors the process of peptone formation. When the stomach is empty its mucous membrane is of a pale greyish color and covered with a thin layer of mucous. The introduction of any substance, more especially food, leads very promptly to the dilatation of the blood vessels of the mucous membrane, which consequently becomes red in color and also leads to the copions secretion of the gastric juice. The gastric secretion may be produced by the feelings or emotions through connection with the higher centers in the brain. The dilatation of the blood vessels and the consequent secretion of the gastric juice is a reflex action similar to that which produces the flow of saliva.

If the vagi are divided during the digestive process the mucous coat becomes pale and stimulation applied to the central end of the divided nerve produces the dilatation of the vessels in the membrane. Afferent impulses, therefore pass from the gastric mucous membrane along the vagi to a center in the medulla, inhibiting the action of the vaso-motor center governing that region, resulting in diminished nervous impulses to the stomach blood vessels, producing dilatation. Efferent impulses pass along the fibers of the sympathetic to the ganglia in the walls of the stomach. These ganglia exert a local influence upon the calibre of the blood vessels and perhaps also the activity of the corpuscles in the gastric juice. Sensory impulses may also arise in connection with the mucous lining of the mouth by the stimulation of food. Thus any substances or acid in the mouth produces gastric secretion. Local centers seem to exist in the stomach, influencing the blood vessels and the secretion. By the general influences of temperature, the stomach movements and the direct action of the gastric juice, the food contents become so changed as to be prepared for absorption. The result of these influences on the food is to form a semi-fluid, heterogeneous mass, the chyme. This has an acid reaction with an acid odor and differs in color according to the character of the food. It consists of water, salts and sugar converted out of starch by the salival action, the remnants of starch left over from the salival process, fatty substances which have been dissociated from the food or liberated from the animal cells, albumin in the various stages of development into the peptones and the undigested and the indigestible matters left over after the action of the digestive juice. There are two stages, thus, in the digestive process in connection with the gastric juice. 1st. A short period during which the saliva acts upon the starch found in the stomach in fermentation, and 2d. A longer period during which the peptones are developed under the action of gastric juice. The first stage depends upon the acidity of the juice; if the juice becomes acid to the extent of .5 per cent then the salival fermentation ceases, this acidity of the gastric juice retarding butyric fermentation, and

lessening the amount of hydrogen in the stomach. There is found in the stomach, always certain quantities of gas, either from the air taken in with the food or the air generated in the intestinal organs. The O from the air taken in by the deglutition becomes quickly absorbed so that in the stomach the gas is deficient in O and rich in CO_2. The gastric juice acts differently upon the different food substances. Milk becomes rapidly coagulated, the saccharine and salt substances found in solution being absorbed, the fatty substances being freed from the milk cells and the casein changed into peptone. The coagulation of milk is produced by the rennin ferment, this ferment being easily destroyed by alkaline solutions. Milk may be coagulated by the addition of gastric juice. If the gastric juice is raised to 60° C or above, no coagulation takes place. The rennin is very powerful, one part coagulating 800,000 parts of milk. The milk curdles by the contact with the mucous membrane. When a calf's stomach is dried and a rennet is produced, it coagulates milk very rapidly. This is due to the existence of an enzyme rennin zymogen which exists in all normal stomachs. The rennin acts upon milk proteids or casein, changing it from a soluble to an insoluble curd. There must be present lime salts. Casein is a nucleo-albumin which under the influence of the rennin becomes hydrated and is divided into two simpler bodies, para-casein and whey. The para casein with the lime salts form the curd or clot. The casein may also be curdled by excessive acid.

If the milk stands for a length of time, lactic acid is formed under the bacterial action upon the sugar, producing casein in the coagulated form. The rennin ferment does not act upon any other substance but the milk. It is important in connection with the milk because of the nutritive value of casein. After the casein has been coagulated it is acted upon by pepsin in the formation of proteoses and peptones. Gelatin is acted upon by pepsin just as in the case of albumin. In the formation of the products of gastric digestion in connection with the pepsin there are formed gelatoses and gelatin peptones. When the gelatose condition is reached the pepsin is said to yield to the tripsin of the intestinal juice which completes the peptone formation. The gastric juice does not act directly upon the carbo-hydrates; hence, it does not act upon starch There is, however a partial digestion of the carbohydrates of the stomach as the carbohydrate food is thoroughly insalivated but it is subject to ptyalin action before the acidity of the stomach becomes complete. This however, is insufficient, as the acidity becomes so great as to destroy the ptyalin. Gastric juice does not act upon dextrose. It has been stated that cane sugar is subject to the action of the invertin ferment in the stomach, being transformed into dextrin and laevulos, a process that is completed in the intestinal digestion. In a stomach that is unhealthy, where much mucus exists there is a free conversion of cane sugar to dextrose. The gastric juice has no direct action upon the fats. There is no splitting or emulsification of the fats in the stomach. The fats, however, are brought under the influence of a higher temperature that is sufficient to melt them, so that in liquid form they become mixed with the solid food and ready for easy digestion in the intestines. In the case of proteids we have the chief action of the gastric juice. Among these are fibrin, insoluble in water, which becomes swollen and dissolved under the gastric juice, forming a clear fluid which is changed into peptone. Coagulated albumin insoluble in water becomes swollen and gradually breaks up, being reduced to a soft mass which becomes peptone. Acid albumin, including syntonin, insoluble in water and soluble in dilute

acids and alkalies becomes converted into peptones. Coagulated proteids present the change under the influence of temperature, being insoluble except in strong acids. Egg albumin coagulates at 75° C. The gastric juice very rapidly absorbs these coagulated proteids even when insoluble by fluids.

In the case of animal muscles a dissolution takes place in the connective tissue between the fibers, exposing the transverse striæ. In this way the fibers are broken into pieces and thus dissolved into their elementary substances. The ligamentous, tendinous and cartilaginous tissues dissolve more slowly, particularly if raw. After being cooked they are acted upon very much like gelatine. The gastric juice does not affect the corny tissues, such as hair, nails and skin. The elastic tissues may be dissolved under lengthened digestion yielding up an elastin peptone. The red corpuscles become disintegrated, the hæmoglobin being separated into haematin and globulin under the influence of the gastric juice, the globulin being transformed into peptone. Bones are not dissolved but the acid of the gastric juice extracts some of the salts leaving the bone in a honey-combed condition. Vegetables in their natural condition are indigestible because of the enclosure of the substances with in a cellulose covering, the cellulose being unchanged by the gastric juice. After being cooked the cellulose yields, liberating nutritive elements such as starch, sugar, etc., setting them free to the action of the gastric juice. Some of the salts are dissolved in the juice, such as phosphates of lime and carbonates, this dissolution yielding CO_2 in the case of the carbonates. Bone when broken up yields the salts, the organic substances yielding gelatin peptones. Experiments have been made to test the rapidity of the digestive process. In artificial digestion the process is much slower than it is normally in the stomach. The rate of digestive action depends upon the food, its nature and also upon the division that takes place in the food, so that if the division is increased so as to increase the superficial area of the food with which the juice comes into contact the process is assisted. Fluids are quickly absorbed, the solids contained in the fluids being concentrated before coming into contact with the gastric juice. The solid substances of food are normally very quickly subjected to digestion. It is estimated that within 30 minutes after a meal is taken the food is changed into chyme, the stomach being emptied within two or three hours. Various experiments have been made in the attempt to discover foods easily digested.

Beaumont found that tripe and rice digest in one hour; eggs, apples, trout, fish, salmon and venison in 1½ hours; milk, barley, liver, fish and tapioca in 2 hours; lamb, pork and turkey in 2½ hours; mutton, fowl and beef in 3½ hours and veal in 4 hours. This does not indicate the nutritive value of the foods, because rapid digestion does not always indicate that the food is nutritious. In the case of a dog fed upon animal food it has been found that digestion begins immediately, continues active during the first two hours then gradually diminishes in activity until the 12th hour, when the digestive action is completed. When the food passes to the stomach there is a flow of gastric juice, the flow beginning even before the food reaches the stomach, the stomachic movements increasing the flow. As digestion progresses, the acidity increases also. By the action of the gastric juice, there is a breaking up of the food so as to form the soluble chyme. This acid chyme consists of dissolved proteids, proteid particles, fatty particles and small lumps of food substances. When the chyme is filtered so as to remove the solids from the fluid it is found to contain salts,

pepsin, hydrochloric acid, sugar peptones and para-peptones, the last three varying in quantity. As digestion proceeds the chyme is ejected through the pyloric orifice into the duodenum, the length of time elapsing before this takes place depending upon the nature of the food, whether solid or liquid, and also upon the nature of the solid food. The normal passage from the stomach to the duodenum in the human subject taking place from 1 to 5 hours after the food is taken, great variation being found in the nature of the change taking place and the length of time necessary for such a change. Some of the peptone formed becomes absorbed without passing into the intestines. In the passage of the food to the stomach considerable quantities of air pass into the stomach. Part of this is driven out in the form of gas, this gas consisting mainly of nitrogen and $C\ O_2$, the O being absorbed in the stomach. Some of the $C\ O_2$ is diffused from the blood and some arises from the fermentation changes taking place in the stomach and in the intestines.

SECTION IX. Modifications of Digestion.

The question is asked in Physiology; "why does the stomach not digest itself?" The stomach of another animal will be readily digested. If the animal is killed, the stomach, itself, may be subjected, at least partially, to digestion, if the normal body heat is kept up. Even in the living subject if the circulation is cut off from a portion of the stomach, as in the case of intra-vascular blood clotting, or ligaturing the blood vessels, the gastric juice will attack thc stomach itself, resulting sometimes in perforation of the stomach. The stomach of another animal is freely digested in the stomach under the influence of the gastric juice. Some have suggested that the vital principle protects all the living organs, such as the stomach and the small intestines, from the action of their own secretion. This does not explain, however, the protection, for it has been shown that the leg of a living frog may be introduced into the stomach through a fistula without severing its connection with the living body, in which case the digestive process will go on. The vital principle is such an indefinite quantity that this is really no explanation of the fact of the immunity of the stomach from its own secretion. Others have suggested that the epithelial lining of the stomach protects it, or that the blood, which is alkaline in its nature, by freely circulating in the organ, neutralizes the acidity of the juice, preventing the digestion of the stomach. The stoppage of the blood withdraws this element and permits of the action of the secretion upon the stomach. In cases where death is sudden, post-mortem examination gives evidence of the partial digestive action in the corrosion of a portion of the lining of the stomach. This corrosion extending even to the proximate organs, such as the diaphragm and the liver. This view does not explain the protection afforded to the intestines against the action of the pancreatic juice. The immunity probably arises from the living properties of the organ, the stomach and intestines, the organs being arranged so structually as to be capable of resisting in normal conditions, the digestive action of its own secretion.

What are the conditions that favor digestion? Aside from individual characteristics which play an important part in the digestion of food, digestion depends upon a number of circumstances which affect the gastric juice: 1st, the amount of food taken and the nature of the food. In order to promote digestion the stomach needs to be normally dilated. This, of course, implies a moderate supply of food. 2d. Sufficient time should elapse between meals so as to permit the food to be completely digested

before new food is introduced into the stomach. 3d. Sufficient exercise both before and after eating assists digestion. This means moderate exercise, because violent exercise is dangerous and against digestion. 4th. The psychic conditions also influence digestion. Disturbed conditions interfere considerably with digestion. Mental equilibrium, therefore, is a favorable condition. 5th. The physical health of the body is also a necessary condition of proper digestion. 6th. Age and the changes in life affect digestion. Digestion is more active in the young than in the old, the changes of life, whether in regard to changes of avocation, temperature, or the normal changes in life influence digestion. The stomach's function normally is to act upon the food by chemical and physical processes, so as to prepare the food for later digestive stages in the intestines. The stomach first concentrates the food substance into a semi-fluid substance representing partially digested as well as the undigested food matters, to be more completely digested in the intestines, called the chyme.

Gastric digestion is largely preparatory, therefore to pancreatic digestion under the influence of the trypsin ferment. The transformation in the stomach does not pass beyond the proteose condition to any great extent, as the peptic digestion is largely preparatory for the triptic digestion, in the intestine, the trypsin being much powerful than the pepsin. According to this, a human being can live without a stomach. We have to give up the idea of the stomach as a vital organ, as the stomach has been entirely removed, the oesophagus being united with the small intestine. Dr. Schlatter of the University of Zurich recently removed a woman's stomach, joining together the approaches to the stomach from the two sides. He reports his patient well, and able to enjoy health without any stomach. Some think that this is not a proof of the ability to live without the stomach normally, as the stomach in this case was so impaired as to be useless in any case. It gives evidence, however, of the extension of the principle of functional sympathy to the stomach.

The digestive process is modified in some animals. In the stomach of the pig we find two parts, one part on the left side continuing the oesophagus, and the other part on the right side forming the stomach proper. In the former part there is a finer mucous lining much less moist with no glands but covered over with small papillary eminences. In the other part the mucous lining is very thick, containing glands very much like the fundus glands.

In the horse the stomach is very small compared with the amount of food that is used. The right portion is the true stomach, the left portion being the oesophagal part covered with a layer of mucous membrane, very white in color. The pyloric orifice is much less tightly closed than in the human subject permitting the free passage of the food substance into the small intestine. In the ruminating animals, the stomach is much more complex. There are four parts or sacs. 1st, the rumen, 2d, the reticulum, 3d, the omasum, 4th, the true stomach. The rumen is a very large sac covered with mucous containing very large conical papillary eminences. This is connected with the lower end of the oesophagus and also with the reticulum, being divided from the latter by a strong band of fibers, from the omasum and the true stomach, similar to those found in the human subject in connection with the cardiac part of the stomach. The reticulum is in the form of a net-work consisting of a large number of cells, the muscular coat being very strong, and its fibers being continuous with the oesophagus. There are three orifices in the reticulum; one into the rumen, another one

298 into the omasum, and another to the oesophagus. The omasum has a fine wall with two openings into the reticulum and the true stomach. The mucous lining consists of leaves or flaps folding over into the sac, these being covered round papillæ. The true stomach is like the stomach in other animals with the fundus and plyoric glands. The food when roughly broken up and forming boli passes down the œsophagus into the rumen. Fluids may pass immediately into the omasum ; if the amount of fluid is excessive, a part may pass to the reticulum, the free watery fluids thus passing to the reticulum while the more viscous fluids adhere to the œsophagus opening or enter into the omasum. The fluid is mixed with saliva passing into the rumen where the food is moved about and broken up and softened, fermentation taking place. After the complete mixing rumination begins. The action is almost identical with vomiting. The ruminal muscular walls contract, the reticulum and diaphragm also contract with the muscles of the abdomen, resulting in the driving of the food into the mouth, the nasal openings being closed. The food now becomes masticated and insalivated, afterward repassing down the œsophagus, passing into the omasum, the more fluid matters passing almost directly into the true stomach, while the rougher elements are passed through a process of filtration among the folds of the omasum. The fluid that is extracted passes into the true stomach, and the solid matters are also driven into the true stomach by the force of the contraction of the walls. In the true stomach digestion proceeds as in the human stomach.

SECTION X.---Digestive Processes in the Small Intestine.

The chyme formed in the stomach is carried through the pyloric opening into the small intestine by peristaltic action. These peristaltic movements take place from above downward, the undulation beginning at the pylorus and extending down, although there are contractions originating all along the intestine. These peristaltic movements take place successively with intervening periods of rest. These movements secure the slow passage of the chyme along the small intestine and its mixture with the three juices, the bile, the pancreatic and the intestinal juices which act together upon the food. There is also a process of absorption taking place in the intestines, the water, fatty and soluble matters being given up in the passage through the intestine. The muscles of the small intestine are arranged in two layers, an inner circular and an outer longitudinal between which and the submucous coating are the nervous plexuses. The muscular arrangement is the same as the stomach and therefore the peristalsis is similar. The small intestinal movements consist of regular and successive peristaltic contractions from above downward, the calibre of the intestine being lessened. There is also a contraction longitudinally in the tube so that lengthwise it becomes shorter. When the contractions become violent longitudinally, then the contraction takes place by loops. These contractions are due to the contraction of the circular fibers and the longitudinal fibers respectively, both acting simultaneously producing writhing movements. These represent the peristalsis moving about 10 to 12 mm. per second and the pendular movements. The peristalsis consists of the contraction of the intestinal walls beginning at the upper part and extending downward section by section, the portions behind relaxing. This pushes forward, the contents of the intestine. The contraction takes place chiefly, if not altogether in the circular layer. Anti-peristalsis consists of a movement in the opposite direction away from the intestine toward the stomach and gener-

ally occurs in abnormal conditions. It has been reported that certain substances introduced into the rectum move upward by such a kind of movement. That the normal movements is from above downward has been shown clearly by some experiments in which, after dividing the intestine, it has been sutured with the lower end upwards. In cases in which death has taken place, there has been found a great accumulation of matter at the upper end, indicating the reverse of the movement. By opening the abdomen the peristaltic movements have been observed running rapidly along the intestines. This, however, is somewhat abnormal, due to the stimulation of the air as the normal peristalsis is slow and gradual. It has been estimated that during rest it goes at the rate of one centimeter per two minutes. During digestion, and especially during exercise the movement is very much more rapid, about one centimeter in 20 seconds. A question has arisen as to the origin of the peristalsis. At each contraction of the ~~antuml~~ plyori the chyme is ejected in to the duodenum originating at the same time the peristalsis that moves slowly along the walls. The passage takes place probably by progression from cell to cell in the circular coating, the distribution being due to the conduction from layer to layer. This is not sufficient to explain the action as the anti-peristalsis would require an explanation. Possibly this muscular action is aided by the nervous impulses passing from the local ganglia. Besides peristalsis, we find pendularicity. This is named from the fact that has been observed that on exposing the intestines there is an oscillating movement of the intestines. These are supposed to be due to the rhythmic contractions of the longitudinal muscles. These movements are supposed to be chiefly of value in maintaining the normal circulation of the blood in connection with the intestines and in preserving the blood pressure in the portal veins. The peristalsis usually originates at the pyloric orifice. It may also originate along the course of the intestines always moving downward. In the intestinal coats there are two nervous plexuses, the one in the connective tissue of the submucous layer and the one lying between the two muscular layers. There are also visceral fibers from the pneumogastrics and the splanchnic sympathetics. By the severance of the intestine from nervous connection with the central nervous system and stimulation of the intestine the peristaltic action may be produced indicating that the ganglia within the intestine act as independent centers in producing these movements. The vagi on stimulation preduce intestinal movements and are therefore said to be motor fibers. There may be, however, inhibitory fibers, although the motor fibers seem to prevail. These movements depend not only upon nervous stimulation but also upon the condition and amount of the blood supply and the peristalsis may be excited by mechanical or electrical stimulation. The peristaltic action is increased by anaemic and also by plethoric conditions of the blood. In both cases there is an excess of CO_2 and a deficiency of O, the gas acting as a stimulant.

When the circulation is partly suspended or when severe hemorrhage withdraws a large quantity of the blood, the movement is increased. During the digestive process, there is an extra blood supply, this acting as a stimulant upon the action. If the stimulation is increased to excess paralysis ensues, and the action is suspended. An excessive blood flow amounting to conjestion and inflammation have the same effect, the muscular walls becoming dilated when filled with gases. If the pneumogastrics are stimulated, the action is increased, whereas, the stimulation of the sympathetics stops the contraction, indicating that the pneumogastrics act as an accelara-

tor of the centers in the intestinal walls, while the sympathetics inhibit the action of these centers. This inhibition depends upon the character of the blood. It is said that the sympathetics for the small intestine arise from the spinal cord from the 6th dorsal to the 1st lumbar, spinal nerves passing to the sympathetic chain through the splanchnics, then to the semilunar plexus. The large intestine is supplied from the 2nd to the 5th lumbar spinal nerves and through the sacral nerves, the nerves passing through the hypogastric plexus and producing contraction of the muscles. If the blood is normal as between arterial blood and venous blood inhibition takes place, but if the blood becomes venous inhibition is changed into acceleration. This seems to indicate the presence of two kinds of fibers, motor and inhibitory in the sympathetics, the inhibitory fibers being counteracted by the venosity of the blood. The higher psychic centers may also influence the peristaltic action as in cases of emotional conditions and nervous diseases, producing constipatory conditions. The stimulation aroused by strong emotions, originating in the brain, influences the vaso-motor center causing contraction of the vessels in the abdominal region, resulting in the anaemic condition of the blood, giving rise to strong peristaltic actions. The nerves regulate the intestinal movements from or through the central nervous system. Their pathway through the system is obscure, the connection, however, reaching the psychic centers. If the nerves are all divided so as to cut off the intestine from its nervous connection, the muscle contraction is not interfered with. Normal peristalsis seems to be independent of nerve control, although the regulation of blood will follow the nervous system. It seems therefore, that peristalsis normally in the intestines may be accomplished independently of the central nervous system, the nervous system being regulatory of its action much in the same way as all the other organs are regulated and controlled by extrinsic nervous connection. Such movements of the intestines may be stimulated by chemical action upon the intestinal walls, for example, potassium salts produce contraction where the potassium is applied. Sodium salts produce the same away from the point of application, spreading downward like normal peristalsis. If the blood supply is cut off and then suddenly allowed to return, strong peristaltic movements follow. Sometimes dyspnœa originates peristalsis, or quickens the rate of already originated peristalsis, acting through the central nervous system. O in the intestine arrests and CO_2, H_2S increase the peristaltic action, similarly acetic and formic acid, developed under the influence of bacterial growth produce stimulation of the peristalsis.

SECTION XI. The Liver and Bile.

The liver represents the largest of all the body glands weighing from 1.4 to 1.7 kilograms, representing about 1-35 of the weight of the entire body, although greater in fœtal and early life. The main portion of the gland consists of, first, the hepatic duct arising from the transverse liver fissure, joining with the cystic duct at the lower end as it comes from the gall bladder, uniting to form a common duct. 2d. The gall bladder consists of a conical shaped sac, the fundus being directed downward and forward extending beyond the anterior part of the liver and the lower end, giving rise to the cystic duct. 3d, The common bile duct is formed by the uniting of the cystic and hepatic ducts extending to the lower part of the duodenum, opening into the bowel by an opening common to it and the pancreatic duct. This opening is so arranged that there is no regurgitation of intestinal contents into the duct. The lobules of the liver get their blood

supply from the portal vein which forms the main channel of the veins of the stomach, pancreas, spleen and intestine. All the blood passes through these entering the liver. The blood from the portal ~~liver~~ holds in solution soluble proteids and carbo-hydrates absorbed during alimentation and these are brought into contact with liver metabolism. The hepatic artery furnishes it with arterial blood from the general systemic circulation. The liver structure is peculiar, the one side of the gland cells being turned in the direction of the main gland cavity. The blood capillaries are closely connected with the hepatic cells, on several sides these blood capillaries never coming into close relation to the bile capillaries which carry off the bile secreted in the cells, or into relation with the ducts. The blood capillaries pass along the margins of the cells and the bile capillaries along the middle of the side. In this gland, therefore, the blood capillaries are very closely related to the secretory cells. These hepatic cells are of irregular shape, with angular edges. having no cell wall. While fasting the cells are small, during digestion they are larger. The lymphatic vessels accompany the branches of the portal vein, forming spiral plexuses around these. These lymphatics enter into the lobules around the blood capillaries and around the minute veins. The liver nerves arise in connection with the cœliac plexus, and from the pneumogastrics, chiefly the left one. They join the liver in close relation with the hepatic branches. They are found in connection with the local ganglia some of the nerve fibers ending in the hepatic cells. The lower is very important from the standpoint of alimentation, this action depending largely upon the character of the cells. Thus, there are two main questions for discussion in connection with the liver, the formation and character of the bile and the metabolism connected with the formation of urea and glycogen which we will discuss in connection with excretion and metabolism.

1. Bile In the liver we find a number of lobules, each lobule being supplied with blood from the portal and hepatic circulations. From the portal circulation there comes blood which has been circulated in the stomach and intestines bearing substances absorbed from those organs, while the hepatic cir culation conveys arterial blood ~~from~~ the nutriment of the organ itself, its tissues and its vessels. From the portal blood the lobular cells secrete substances which are given off into the duct for the formation of bile. This blood when robbed of these matters returns through the ~~heptic~~ vein to the heart. The portal blood entering the liver contains a larger amount of albumin, hæmoglobin, fat, salts and water and less cholesterin and lecithin than that returned to the heart. The portal blood brought to the liver also contains saccharine matter taken from the carbohydrates, while the blood returned to the heart contains sugar from glycogen. The lobular cells, therefore, are the seat of bile secretion and also of glycogenesis, urea formation, etc. The substance of fresh liver is alkaline in reaction, becoming acid after death. In it we find various proteids. The hepatic cells also yield 1 to 1½ per cent of glycogen, fatty matters, urea, uric acid, cholesterin, jecorin together with organic salts, potassium, sodium calcium or magnesium and iron together with such metallic substances as copper, mercury lead, etc., extracted from the food. The bile is both a digestive secretion and an excretion, the former being used in the digestive process in the small intestine and the latter being excreted as an excess in the fæces. Thus, the bile is connected with the physical and chemical changes in the intestine. Bile may be best secured by means of a fistulary operation, although it is difficult and dangerous. The bile when fresh is a fluid of a

golden red or a brownish yellow color in the human subject. After being exposed to the air it becomes a dark brown color. It has a strange odor especially if hot and a very bitter taste. It contains some gall cells and some mucous corpuscles usually. Its specific gravity is about 1030. In the gall bladder the bile is mixed with a considerable quantity of mucus of a darker color and very viscous. If dissolved in sulphuric acid it appears fluorescent, being pink in transmitted light, and green through reflected light. After administering anæsthetics an animal's abdomen may be opened and the bile duct ligatured close to the junction with the cystic duct and also close to the intestine. Between these two ligatures there is a division made. The fundic portion of the gall bladder is stitched to the abdominal wall, the fundus being opened and a tube inserted into the gall bladder. In this way the bile may be secured. The bile yields in the case of the human subject from 13 to 15 per cent of solid matter. On the analysis of 100 parts of bile there has been found 86. 3 per cent water, 13.7 of solids and of these solids 8 .2 per cent of bile salts, 2.5 per cent of cholesterin, lecithin fatty substances, 2.2 per cent of mucus and bile pigment and .8 per cent of the inorganic salts. The bile varies in different animals and at different times in the same animal. It is effected by the length of time it remains in the gall bladder, its reaction is neutral or alkaline. It is characteristic that the proteins are not present. Among the solid matters we find, first bile acids. Taurocholic acid is found in great abundance and glycoholic acid in small quantities in human bile. These combine with sodium to form salts, in the formation of the sodium taurocholate and the sodium glyoholate. They are insoluble in ether but soluble in water or alcohol, the a queous solutions being alkaline in reaction. Both acids contain cholalic acid. 2d, the bile pigments, bilirubin and biliverdin. The former is supposed to be derived from the red coloring matter of the blood being identified by some with hæmatoidin, one of the hæmoglobin derivatives. The latter is derived by an oxidation process from bilirubin. The biliverdin is formed by exposing to the air in a shallow vessel an alkaline solution of bilirubin. The bilirubin is kept in solution in the bile by the sodium salts of the bile acid. 3d. Cholesterin is kept in solution in the bile by the bile salts. This is the chief element found in gall stones. Though fatty looking it is in reality an alcohol, being soluble in hot alcohol and dissolved by the bile salts so that it is in solution in the bile. 4th. The mineral salts including chiefly chloride of sodium, potassium and the phosphates of sodium, calcium and magnesia with traces of iron oxide, silica and copper. In 100 parts of bile Jacobsen found about .1276 of potassium chloride, 2.45 sodium chloride, .598 phosphate sodium .418 carbonate of sodium and .81 per cent of sulphur and .167 phosphate of lime. 5th. The gases of the bile contains sometimes a large per cent of CO_2 ranging from 5 to 60 per cent, and small quantities of O and N.

The secretion of the bile is continuous, but the quantity formed when the stomach is empty is small. Only a low pressure is necessary for bile secretion, for the diameter of the hepatic artery is small and the secretion is not due to the pressure, not being a process of osmosis but of secretion in the hepatic cells.

Heidenhain estimates the pressure of the flow of bile along the ducts to be 15 mm. of mercury; even this small pressure is larger than the pressure in the portal veins; hence, the secretion cannot be due to mechanical pressure. Even when an animal is deprived of food secretion continues. It is largely increased during the digestive process, this secretion beginning to increase almost immediately after taking meal, reaching its highest point

about the third or fourth hour and after gradually diminishing for a few hours. then increases till about the ninth or tenth hour after which it slowly lessens. The amount of food influences the bile secretion, especially in the case of animal food when the secretion is increased, a food consisting very largely of fats diminishing the secretion. According to some experiments there is secreted about 10 grams of bile to every kilogram of body weight daily in the human subject, indicating that there is an active metabolism in the hepatic cells. The secretion is also affected by the blood flow in the capillaries. If blood is injected into the veins it is increased, and if blood is taken from the arteries it is diminished. If the portal vein is ligatured the secretion will diminish until it ceases altogether, causing death. If the hepatic circulation is obstructed the secretion increases and then diminishes. While the blood pressure in the capillaries does not cause the secretion the velocity of the blood current through the capillaries has a bearing upon the secretion, because the action of the hepatic cells depends upon the circulation of the blood through them. The bile is secreted by the hepatic cells and even the water does not depend upon simple filtration because the pressure of the portal vein is less than the pressure in the bile ducts. The activity of the cells depends upon amount of blood received into them. If the blood pressure in connection with bile ducts increases beyond 15 mm. of mercury the secretion of bile continues, but its flow is arrested in the ducts, the bile flow taking place into the blood through the lymphatics, the bile pigment giving to the skin the peculiar jaundice color. The same result may follow, from a ligature of the bile duct, in which case the process requires three or four days. Associated with jaundice is a condition of constipation due to the lessening of peristaltic action, the fæces being hard and yellow colored with an offensive odor. An effect is noticeable upon the activity of the heart, which is much diminished, on account of the lessened activity of the intra-cardiac nervous mechanism and also the respiration becomes slower. The blood corpuscles become dissolved under the action of the bile salts, the pigment being found in the blood and hæmoglobin with albumin in the urine. The formation of bile takes place in connection with the hepatic cells which are closely related to the blood and bile capillaries. The cells are polygonal in shape, the surfaces by juxtaposition, forming grooves, around the sides being found the bile capillaries corresponding with the number of sides, at each of the pointed surfaces being found the blood capillaries. The bile capillaries are much smaller than the blood capillaries that the bile is formed in these cells is evident from the fact, 1st, that if the liver is removed the bile acids and the bile pigments are not found in tne blood, and 2nd, the bile acids and bile pigments are not found in connection with any other part of the body and if they are found anywhere else they originate in the liver. The taurin, glycocin and cholalic acids are separately formed and when so formed unite to form the bile acids.

When the blood corpuscles are disintegrated the hæmoglobin is taken to the liver and is converted to the bilirubin, the iron separated being retained in the liver and used in the formation of new hæmoglobin. The bile pigments pass to the duodenum and are mixed with the food. Neither biliverdin nor bilirubin are found in the fæces, but a hydro-bilirubin. The biliverdin arises in connection with the disintegration of the hæmoglobin. In connection with the blood clotting the bilirubin assumes the crystalline form of hæmatoidin the same as bilirubin. If solutions of hæmoglobin are injected into the portal vein the amount of bilirubin is increased in the liver.

The bile salts in solution have the same effect. This substance when hydrated appears in the fæces as stercobilin and in the urine as urobilin. The formation of bile acids takes place in the liver cells. If the bile duct is ligatured the bile that is found is reabsorbed, the acids being found in the blood and urine. It is difficult to determine from what substances they are formed. Nitrogen found in the glycohol and taurin and sulphur in the taurin indicate that some albuminous substance is broken up in their production. These products, as we have said, are absorbed and again through the hepatic circulation, are secreted by the liver. The chief value of these acids is possibly to form a stimulus for cell activity. It is supposed that in addition to this they act upon cholesterin, dissolving it for excretion, and also that they act upon the fats producing an increased fat absorption. When the bile is formed in connection with the cells it is pressed out partly in connection with respiratory movements and partly by muscular activity in connection with the larger and smaller ducts and the gall bladder. Respiratory movements produce pressure upon the liver and gall bladder, inspiration assisting the blood flow away from the hepatic veins. The bile secretion is continuous. It is normally small when the stomach is inactive, immediately after taking a meal the amount is very much increased and this increase is maintained for some hours. It is said that in 24 hours, 2½ pounds are secreted and that the secretion is much more plentiful after partaking of proteid food. The bile accumulates in the gall bladder and its ejection into the intestines appears to be a reflex action, the stimulus being the acid chyme, for it is known that the entrance of an acid into the small intestine is at once followed by a gush of bile, while no such results follow the admission of an alkaline fluid into the small intestine. Nervous influence upon bile secretion is very obscure. The voso-motor fibers are found in the pneumogastric and the splanchnic sympathetics. If the splanchnics are divided or the pneumogastrics in the neck are cut the liver passes into a state of congestion.

Pfluger says that after the division of all the hepatic nerves bile secretion continues; when the bile comes into the small intestine it has very little effect upon the chyme. In the large intestine a part of it becomes decomposed, the balance being excreted in the fæces. The biliary acids are divided up into glycocin, cholalic acid and taurin, the bile pigments into hydrobilirubin and the urobilin to be again absorbed so as to form the pigment, a small part becoming biliprasin. Part cf the urine is united with alkalies in the formation of soaps. The fæces excrete bile acids, cholesterin, mucin and lecithin. A large part of the bile salts are absorbed again, all the absorbed elements returning to the liver to form other compounds.

If in an animal, the bile is hindered from entering the intestine, emaciation follows, but life may be preserved if a large quantity of food is given producing a great appetite. Upon the albuminous or proteid constituents of food bile has no effect unless that by its alkaline reaction it neutralizes the acid chyme and causes the precipitation of any peptone present. The bile prevents the digestion of albuminous matter by the gastric juice at the same time separating the peptones from albumin and preparing the albumin for the digestion action of the pancreatic juice. Upon the carbohydrates the bile has almost no effect, its only effect being to transform the starch solutions into sugar. Upon the fats, bile has considerable digestive power. When the fatty acids are liberated by the pancreatic fluid the bile combines with them to form soaps or emulsions. The fatty acids thus decomposed dissolve the bile, salts uniting with the alkaline bases to form the soaps,

Ald.) Stimulate—Plank action

these soaps aiding in the emulsification of fats. These soaps assist in the fatty emulsification of the fats in the intestines, the bile acids causing the neutral fats to become soaps. The fats readily pass through the mucous membrane moistened with bile, hence bile assists the absorption of fats by moistening the mucous membrane of the intestine. Bile also stimulates the peristaltic movements of the intestine. If the bile is diminished the peristaltic action is lessened and the fæces become dry, hence a large increase of bile produces diarrhœa. The bile is freely putrefied although it lessens the putrefaction of the fæces by increasing peristaltic action and thus throwing quickly the putrescent matters out of the intestines. If these matters remained long putrefaction would follow even though the bile is present. Bile has an important bearing on excretion, by removing the waste products of metabolism such as lecithin and cholesterin. The bile acids and pigments become reabsorbed and hence are of further use in the metabolic process. Its chief digestive function is in connection with the fats. It first assists in splitting up the neutral fats and then aids in their emulsification and lastly assisting fat absorption.

If a fistula is introduced so as to extract the bile the fæces are found to contain a large quantity of fat. This is due in some way to the action of the bile acids upon the fats or rather upon the epithelial cells so as to make them active in absorption. In addition to this the bile acts as a destroyer of the pepsin ferment activity. When the chyme comes into contact with the bile and the pancreatic juice it becomes alkaline, preventing the pepsin action and developing the precipitation in connection with the formation of some proteids and acids.

SECTION XII. Pancreas and Pancreatic Juice.

The pancreas is an extended narrow gland lying across the abdominal wall back of the stomach and opposite the first lumbar vertebra. The head of it is in contact with the duodenum curvature and the lower end is in contact with the spleen. The pancreatic duct extends along the whole pancreas, opening into the duodenum below the pylorus. The lining of the duct consists of cylindrical epithelium, the wall being formed of solid connective tissue from which small branches arise, ending in the gland acini. The acini consist of short conical cells. The cell form depends upon its functional activity. When digestion begins the disappearance of the granules takes place, the large part of the cell being clear. During inactivity, especially if prolonged, the granular and clear parts are about equal. Blood vessels from the splenic supply the pancreas, together with branches from the superior and inferior branches of the hepatic and the superior mesenteric arteries.

The blood passes off from the pancreas through the splenic and superior mesenteric veins. Around each acinus is a plexus of capillaries. The nerve supply comes from the solar plexus non-medullated fibers extending into the pancreas, their endings being unknown. There are also intrinsic ganglia associated with the pancreas. Most of the experiments have been carried on in connection with artificial pancreatic digestion or fistulae in connection with the dog or rabbit. Heidenhain cut out a part of the duodenum into which the main duct opens, stitching this isolated portion to the abdominal wall to form a permanent fistula. The pancreatic juice may be obtained by the introduction of a canula into the duct. It differs from the other juices mainly in the large proportion of proteids in it. It is a clear, colorless fluid, very viscid, under the influence

of heat becoming coagulated. It has a decided alkaline reaction and contains about 8 or 10 per cent of solids.

Claude Bernard, after anaesthetizing a dog, laid it on its left side, making an incision to expose the pancreas. Opening the duct after isolating it a cannula was inserted, which was passed through the abdominal wall and the wound sewed up. This fluid contains a large proportion of serum-albumin and a quantity of salts, such as sodium chloride, phosphates and alkaline carbonates, together with small quantities of soapy substance and nitrogenous matters like leucin, tryosin and zanthin, etc., and also ferments. The amount of solids depends on the seretion rate, being more where it is slow. It has a specific gravity of 1010 to 1011. During fasting little, if any pancreatic juice is secreted, but as soon as food is taken the secretion of the juice commences and continues for hours.

Herter collected some of the juice from the duct in the human subject and found it clear, colorless, odorless and strongly alkaline, being about 2½ per cent of solids, 1½ of that being organic.

Schmidt found in connection with the dog in 1,000 parts, 979 of water, 20.1 of solids. Of this 12.4 was organic matter and 7.5 salts. Much difference of opinion exists as to the constituents of the human pancreatic juice. It is estimated that in 24 hours over 140 grams are secreted. During the digestive intervals a small quantity is secreted. At the beginning of digestion it seems to be more viscid and easily coagulated, becoming more free and watery at the end of digestion. The use of a large proportion of food and nutritious food increases the secretion both in quantity and quality. The secretion seems to take place under the influence of pressure. When inactive, the pancreas is pale, when active it becomes reddish or pink red, the blood vessels being full and characterized by pulsations. The cells in the gland become larger as the secretion takes place, becoming conical in shape with a definitely clear zone close to the membrana propria with a dark zone next to the cavity. During the active operation of secretion, the interior zone is lessened, the exterior being increased. At the close of the secretion the clear zone is quite small and the dark zone very much larger. The pancreatic juice acts differently upon the different foods. The chief constituents of the food are three enzymes, the proteolytic, tripsin acting on proteids, the amylolytic on carbohydrates, and steapsin on the fats. On starchy foods it acts very actively, rapidly converting by the action of amylopsin starch into sugar, chiefly maltose, more rapidly than during the process of insalivation. Any form of starch is thus quickly acted upon by the ferment of the pancreatice juice.

If some of the pancreatic juice is mixed with starch paste, the starch very soon disappears, maltose and dextrine being formed. The amylopsin acts on the starch; it is said to be similar in action to ptyalin. Hence, some identify the two ferments as one. The products are maltose and the intermediate dextrines, the quantities depending upon the completeness of digestion. It is very important as carbohydrates form a large element of the food. The saliva first acts on them, but it is when they reach the intestine that the chief action takes place under the amylopsin. On fats the steapsin ferment has a two-fold action, (1.) it emulsifies them, the emulsion representing the fatty matters in a fine state of division. If olive oil is shaken up with pancreatic juice there is a minute division takes place slowly. (2.) It splits up neutral fats into their respective acids, and glycerine and the free fatty acids then combine with sodium salts to form soaps. The fats splitting enzyme is called steapsin. Its action has been discovered in con-

nection with the neutral fats mixed with steapsin, the fats breaking up and taking up water producing glycerine and the fatty acids. The steapsin has not been definitely isolated. It is hard to preserve because easily destroyed. If butter is mixed with pancreatic juice, the mixture being kept at body temperature there will be a decomposition of fats resulting in butyric acid. The action of the ferment depends upon the normal temperature and also upon the nature of the fat. All the fat is not decomposed, the larger proportion being absorbed as neutral fat direct into the blood. It seems that the steapsin acts on a small part of the fat, producing fatty acids and glycerine which aids in the emulsification of the rest of the fats so that it is of direct value in digestion. Emulsification takes place when an oil is broken up into minute globlets that are not coalescent, the particles remaining insoluble and distributed in the medium. If oil and pancreatic juice are shaken up the emulsion is produced. This takes place by the formation of the fatty acids which combine with the alkaline salts in the formation of soaps. As the chyme comes into contact with the pancreatic juice a part of the fat is split up by steapsin, forming free fatty acids. These unite with the alkalies and the alkaline salts to form soaps producing an emulsification of the remainder of the fats. The bile is mixed with the pancreatic juice and this mixture facilitates the splitting up of the fats, especially by furnishing alkaline salts in free condition. The emulsifying power of the pancreatic juice depends upon its viscidity, on the presence of carbohydrates and on the formation of the soaps through the action upon the fatty substances. The bile, if present in the pancreatic juice assists in the process of emulsification. The proteids are converted by the pancreatic juice under the action of pepsin into peptones, but the amount of peptone produced does not correspond with the amount of proteid matter acted upon. The conversion is most favored up to 40°C. from 35°C. being retarded by lower temperatures. If boiled it is completely destroyed. Gelatin and other albuminoid substances, under the action of tripsin complete the change to gelatin peptones, carried to the gelatose stage by the pepsin. This is due to the fact that while the albumin is changed into the peptone and a number of other substances are formed, the peptone becomes partly changed into leucin and tryosin, this last being changed into indol and oth- substances which have a characteristic faecal odor. Leucin and tryosin have been found in the intestinal contents and it is supposed that these are formed as a result of triptic digestion. Their physiological value as yet is unknown.

These same bodies are found under pathological conditions in different parts of the body and they are also found as a result of the destruction of proteids by bacterial organisms. Thus, the pancreatic digestion of proteids differs from the gastric digestion of the same substances. For the action of pepsin upon proteids, acids must be present, while the pancreatic juice is most active, when an alkaline is present and it is retarded and hindered by neutralization or acidification, although it may take place if slightly neutral or acid. The conversion of starch into sugar, the action upon fats, the formation of peptones from proteids, each of these results is believed to be due to the action of a special ferment present in the pancreatic juice. This ferment is the proteolytic ferment, trypsin. Trypsin action is increased by heating and lessened by cooling, the normal temperature being about 40°C. If raised above 70 or 80°C, the trypsin is destroyed. By cutting the gland and using glycerine we get a glycerine extract. It is best to use a gland a few hours old, because in the fresh gland we find, not the trypsin but tryp-

sinogen. By the action of trypsin there are formed the proteoses and the peptones but the process is somewhat different. Solids, under the action of trypsin, do not swell but they erode, the indigestible elements retaining the form. The transformation takes place directly from the proteids to the secondary proteoses, by the hydrolytic process, after which the transformation to peptones takes place. Here the action of trypsin produces a number of nonproteid bodies which are amido-acids. The peptone that cannot be further changed, is called anti-peptone, the balance being hemi-peptone representing the final products of tryptic digestion other than the peptones. It is peculiarly active in alkaline solutions, decomposing the albumen. The trypsin is formed by the decomposition of tripsinogen, as it is not found in the pancreatic cells. Under the action of trypsin the proteids are changed into tryptones, or hemi-peptones as Halliburton calls them, differing from the peptones in various particulars. The fibrin in the pancreatic digestion does not swell, remaining opaque and becoming corroded. The peptic digestion is acid, whereas pancreatic digestion is alkaline, being hindered by accidification especially with the mineral acids. If the pancreatic juice is mixed with sodium carbonate to the extent of 1 per cent the digestion is facilitated, playing the same part in triptic solution that hydrochloric acid plays in peptic digestion. If the pancreatic juice is heated to over 40°C and mixed with hydrochloric acid 2-10 per cent, its action is destroyed. The mixture of the bile with the pancreatic juice seems to facilitate its action. By the action of this trypsin ferment peptones, or rather triptones are produced, the great difference being that instead of producing acid-albumin as in the pepsin, there is produced alkali-albumin. Before the final formation of alkali-albumin the fibrin is changed into products that are intermediate between albumin and alkali-albumin. They are readily dissolved in water and by a weak solution of copper sulphate yield in reaction a deep purple red color. The decomposition yields the amido—acids, leucin, tryosin and the odorous substances phenol, skatol and indol. Indol may arise in connection with proteid decomposition under the influence of alkalies at an increased temperature. It is in the alkaline medium that the germs find a field for development under the influence of trypsin. This pancreatic ferment can convert the proteids into peptones unaided by micro-organisms.

On the other hand, leucin and tryosin are not obtained without these micro-organisms. Indol, it is claimed, is produced under the influence not of the unorganized ferments but by the organized ferment, the micro organism being necessary for its production, as in a fluid which yields indol, there is always present some micro-organism. In addition to this by the action of the pancreatic juice we find the nitrogenous product, leucin and tryosin. Under the influence of the pancreatic juice, the proteid acted upon does not yield nearly the proportionate proteid products. When the product of digestion is divided so as to separate the alkali-albumin there is yielded by evaporation crystals of tryosin. If these are taken out and precipitation produced by a second evaporation, leucin and tryosin crystals are deposited. Thus the proteids under the influence of the pancreatic juice divide up into the proteid triptones and into the substanecs that are not proteid or leucin and tryosin. Leucin is a combination of fatty acids and ammonia, whereas tryosin is a phenyl compound closely related to benzoic and hippuric acid. These two represent the fatty acids and aromatic bodies. The pancreatic mixture very soon becomes filled with bacteria. If the ferment is isolated so as to prevent the admission of air germs or if salicylic acid is

used in connection with the juice, the germs are prevented from development and the odor is absent. Thus the pancreatic juice is associated with the formation of indol under the influence of an organized ferment. We have seen that three ferments act upon the carbohydrates, proteids and fats, reducing, splitting up or emulsifying them, the emulsification taking place chiefly in connection with the combination of the three juices, although largely under the influence of the alkali-albumin.

SECTION XIII. Intestinal Juice.

This juice, succus entericus, is believed to be secreted by the glands of Brunner and Lieberkuhn. The information regarding this juice is limited chiefly on account of the difficulty of obtaining it pure. By opening the abdomen and a loop of the bowel cut being across in double section and then by connecting the lower end of the bowel above the part cut across with the upper end of the lower portion so that the intestinal canal is continued, the cut part may be formed into a sac. The Thirry-Vella fistula consists of cutting out a small part of the intestine without injuring the blood vessels or nerves and then stitching the two open ends to the abdominal wall to form a double fistula. By suture the continuity of the intestine is established, the loop being used to collect the secretion. It is a clear, viscid fluid with a palish yellow color and a strong alkaline reaction. The secretion is small and requires stimulation to start it. It is more plentiful in the lower than in the upper part of the intestine. It is freely coagulated by heat and under acid influence, having a specific gravity of 1010. It contains a small per centage of solid, chiefly albumin. mucin, and with the carbonate of soda from .25 to .5 per cent and sodium chloride. The invertin ferment converts the cane sugar into the sugar inverted. It is variously described as having a digestive influence over proteids, fats and carbohydrates; others, however, claiming that its action is confined to the conversion of starch into dextrine and maltose.

The intestinal juice acts upon all kinds of food, its action, however being slow and feeble. The mucin contained in the fluid acts as a lubricator upon the internal surfaces of the intestine, smoothing it so as to permit the contents to pass freely. As soon as the chyme passes into the intestine, the gastric juice ceases to act upon it, the acidity of the chyme producing the flow of bile, pancreatic and intestinal iuices. The alkalinity of these juices neutralizes the acidity of the chyme producing the normal alkalinity in the small intestine. In the small intestine all the food elements become changed so as to be prepared for absorption. The alkalinity is greatest in those layers close to the intestinal wall, the internal layers being slightly acid. The hydrochloric acid of the gastric juice precipitate pepsin and glycocholate, the taurocholate precipitating the albumin not transformed into peptones, the peptones and triptones remaining in the solution. The solution that is formed is thick and glairy. At the upper part of the intestine the chyme is of a pale yellow color due to the bile influence, at the lower part it is much paler. As it passes down the alkalinity increases on account of the action of the three juices, the digestive process being nearly completed, leaving very small quantities of undigested food. Under the influence of the alkalinity the triptone digestion takes place. The viscous solution formed by the bile is dissolved but the pepsin cannot act because of the alkalinity in the solution. The remnants of the starch are changed to maltose, the fatty substances becoming emulsified and the albuminous substances changed to leucin and tryosin. This intes-

tinal secretion has no definite action upon the proteids. The sodium carbonates assist in the emulsifiying of fats. In connection with the carbohydrates it has an important action. There is an amylolytic ferment more plentiful in the upper part of the intestine acting upon the starch and converting it into maltose and dextrin. In addition the presence of the invertin transforms cane sugar into dextrin and laevulose, and the maltose to dextrose. The double saccharines, cane sugar, milk sugar and maltose, which are found commonly in all diets, are acted upon by the inverting ferments so as to form simpler bodies, the absorption taking place finally in connection with dextrose which is the final product of conversion. Gallstones are often formed in the gall bladder, sometimes smaller obstructions being found in the bile passages. The most common kind of gallstone is composed of cholesterin, sometimes with a little pigment, at other times being colored with pigment. These are crystalline in structu.e. Another kind of gallstone consists of bilirubin and calcium, these being dark in color. Sometimes the gallstones consist of bilirubin derivatives and sometimes of inorganic salts. These gallstones originate in a neucleus, the matter being collected around this center. The origin of the stone is found in connection with the bile, the cholesterin or bilirubin collecting together instead of remaining in solution in fluid. During the progress in these various changes the peristaltic action of the muscular fibers propells the chyme along the course of the intestine, the absorption of the soluble matters taking place in connection with the blood vessels and the mucous projections of the intestine. Thus, the chyme is gradually transformed and diminished, these processes preparing it for passage into the great intestine. Very seldom is there any quantity of chyme in the intestine, as it passes quickly in absorption and excretion

The chyme as it passes into the intestine comes into contact with the bile and pancreatic juice, changing the acidity into alkalinity. In the human subject the chyme becomes alkaline before passing far down the intestine. The conversion of starch to sugar which was stopped in the stomach begins again under the influence of the pancreatic and intestinal juices and is continued until the greater proportion is digested The pancreatic juice emulsifies the fats, the neutral fats passing to the lacteals. The bile and pancreatic juice provide an alkaline medium, the pancreatic juice furnishing the fatty acid, and the bile dissolving the soaps. Thus the two juices unite in emulsification in the small intestine, the gray colored chyme becoming in the small intestine whitish cream colored. The pancreatic juice thus assists in the changing of fats for absorption in the lacteals. The bile also assists in this process as the removal of the bile by ligature and fistula seems to retard fat digestion, throwing quantities as it into the faeces. The intestinal juice does not possess large emulsifying power. This was shown by a case in which the duodenum opened by a fistula so as to separate the upper and lower parts. Fats placed in the lower part were hardly subjected to digestion, because of the absence of the bile and pancreatic juices, so that fat digestion is largely carried on by the mixture of bile and pancreatic juice. In the intestine there is formed the substances under the influence of micro-organisms, resulting in indol and indican, so that the action of the combined juices in the intestine is modified by the presence of micro-organisms. It is chiefly in connection with the proteids and carbohydrates that this micro-organic decomposition takes place. From the proteids are formed indol, phenol appearing in the faeces and urine. There are also formed in connection with the proteids ptomaines in the process of putrefaction. The principal action of the micro-organisms is in connection with carbohydrates. As the food passes down the intestine there is present lactic acid formed by

lactic acid fermentation. This is supposed to take place normally in the intestine. The presence of free H in the intestine indicates fermentation changes. If chyme is taken from the intestine and kept at bodily temperature, CO and H will continue to be formed indicating the butyric fermentation process. In this way the sugar becomes transformed to the fatty acid group and may be changed to fat. The H acts as a reducing agent, acting on sulphates and producing sulphides and forming faecal and urine pigments. Thus, in the small intestine proteids are changed to peptones and other substances, starch to sugar, and sugar to lactic acid and fat, these passing into the lacteals or the blood vessels, the remainder being excess faeces or urine.

SECTION XIV. Processes in the large Intestine and Passages to the Rectum.

By the absorption of the soluble elements from the chyme it is lessened in quantity, passing into the great intestine to be subjected to the action of secretion arising from glands similar to those of the small intestine. As in the small intestine there are movements of the intestinal contents due to the peristaltic contraction of the muscular fibers of the intestine. The movement, however, is much slower than in the small intestine as the bowel is not so free, being in the greater part of its extent fixed by the peritoneum. The passage of the contents through the large intestine take a much longer time, than is occupied in the small intestine, although the large intestine is only about ⅓ of the length of the small one. It is estimated that from 12 to 18 hours are occupied in the passage through this large intestine. This length of time includes the long time during which substances continue in the caecum, becoming more solid on account of the water being absorbed.

The sharp ridges projecting into the intestines, divide the intestine into a number of compartments, delaying the passage of the contents. The rectum also accumulates the materials, the sphincters preventing the rapid passage. The movements of the large intestine are essentially the same as those of the small, the movements of the large intestine beginning at the point where the small intestinal movements stop, namely, the ilio-cæcal valve. The movements are more simple because of the absence of the loops and the absence of the muscular fibers, to any great extent. The movement is from sacculus to sacculus along the colon, peristaltic contraction, driving the contents from the one to the other, the contraction of the circular fibers being followed by relaxation of the circular and contraction of the longitudinal fibers in the next succeeding sacculus The edges of the ilio-cæcal valve close the caecum so that regurgitation into the small intestine is impossible. When the fæcal contents arrive at the sigmoid curvature, they are upheld by the bladder and caecum so as to press on the sphincter ani.

The nervous connection with the large intestine is as yet unknown. The excitation of the pneumogastric tends to stimulate, while the excitation of the splanchnic sympathetics does not stimulate the activity of the large intestine. No digestive process goes on in the large intestine. The contents are of a distinctly fæcal character, and are acid in reaction, this being due to the acid fermentation of the intestinal contents and not to any acid secretions yielded by the glands in the intestinal mucous membrane. The secretion of the large intestines is composad largely of mucus, having probably no special enzyme of its own. In passing from the small intestine there are still undigested elements but these are mixed with the enzymes of the small intestine which probably act for some time. In the large intestine the contents are alkaline toward the walls, the secretion of the intestinal glands being alkaline in reaction, while

toward the middle of the intestine and away from the walls they are acid. In the human subject the intestinal changes consist of the formation out of the waste elements of the food of the bile, and other secretions, of fæcal substances. In the caecum these waste matters become closely packed together on account of the absence of the peristaltic action. The fermentation going on produces certain acids, lactic acid, butyric acid, and also the generation of certain gases as H, surphuretted H, etc. The water becomes absorbed by the blood vessels. In this way the intestinal contents become more and more solid, the water being absorbed. The putrefaction changes also give rise to the formation of certain acids, such as palmitic acid, together with the odorless substances, phenol, cresoal, indol and skatol. The bile that passes down into the large intestine becomes changed into taurin, glycocin, cholalic acid which, together with the pigments and acids of the bile are found in the fæces. These fæces have a characteristic odor which varies in the individual and at different times. This aroma arises from the decomposition of the contents of the stomach and intestines. These may be either acid alkaline or neutral. In the case of dieting upon the carbohydrates and faeces become characteristically acid. If the diet is albuminous they become alkaline. The color also varies with the food. The dark color arises in the case of an animal diet. In vegetable diet a lighter color and in a mixed animal and vegetable diet a yellowish brown. In jaundice the fæces become a dark yellow. Microscopic examination discloses the presence of indigestible materials including ligaments from flesh and cellulose, indigested matters as tissues in fragmentary stages. These tissues vary with the diet. Among the other substances found are mucus, fatty cells, starchy globules, fibers in different stages of decomposition, crystals of the triple phosphates.

There may also be found the acids, pigments, cholesterin, excretin and soaps found in connection with the gastric and other juices. In a mixed diet they contain about 75 per cent of water while in diet upon animal food this is usually reduced to 50 or 60 per cent, about 25 per cent being solid matter, of which about 4 per cent consists of salts, chiefly triple phosphates of ammonia and magnesia. The normal human subject is estimated to pass about 150 to 200 grams daily as fæces. This amount, however, depends somewhat upon the nature of the food. In vegetable diet the amount being largely increased because of the amount of indigestible matter, such a diet in same yielding 450 grams. In the large intestine, CO_2 is the chief gas found together with H, sulphuretted H and carburetted H. In the rectum the fæces remain for a variable time and they are expelled as the result of relaxation of the internal sphincter, contraction of the walls of the rectum and of the abdominal muscles assisted by the fixed action of the diaphragm. The pressure of the fæces upon the mucous of the lower portion of the rectum arouses the impulses. If this pressure does not reach a certain limit the sphincter resists the evacuation. If pressure reaches a certain limit there follows a series of reflex contractions at intervals in the rectum, the contraction extending to the sigmoid curvature of the colon. By these contractions the internal sphincter yields, the external sphincter yielding to the will. The sphincter consists of involuntary muscles, having nerve connections with the sympathetic system and from the spinal nerves from the sacrum. The external sphincter ani is composed of striated muscle tissue and is therefore,' at the disposal of the will. Defecation, is therefore, a mixed action partly voluntary and partly involuntary. The voluntary element depends upon the action of the abdominal muscles in the production of pressure. There is a contraction of these muscles similar to expiration but as the glottis is closed the pressure is all brought to bear upon

the abdominal muscles, pushing the contents of the colon down toward the rectum. This pressure does not affect the sigmoid curvature. The spinchter ani protects the anus, the sphincter being normally in the state of tonicity so that there is the capacity of contraction or relaxation depending upon the stimulation. The nervous impulses from the lumbar center kept up the tonic contraction for relaxation follows the division of the nervous connection. If the spinal cord is cut above the lumbar region there is only a slight depression of the sphincter followed by a return to its normal condition. This indicates that the fæcal center is in the lumbar region. This is the center of reflex action depending upon local stimulation and upon the impulses of the higher center under the control of the will. The center may be inhibited and thus the sphincter will relax or it may be stimulated and the sphincter will contract still more. Therefore, in addition to the muscular action there is the inhibition of the lumbar center as a part of the defecation process. Even in diseased brain conditions there is not of necessity, any effect upon the sphincter and if paralysis of the sphincter accompanies cerebral conditions this is due to the reflex inhibition of the lumbar center. These two actions are not sufficient to account for defecation, as to the abdominal pressure is prevented by the sigmoid curvature, so that the sigmoid curvature would remain full of matter. In order to accomplish the emptying of this flexure the peristaltic action of the intestine, flexure and rectum is brought into play. In the rectal peristalsis there is a marked peristalsis of the circular and longitudinal fibers. By longitudinal peristalsis the rectum is shortened, the movement being from above downward. As the anus is a fixed base, this results in drawing down the rectal canal. By circular contraction traveling from above downward the rectal canal is narrowed, resulting in the excretion of the contents. As the large intestine and the sigmoid curvature becomes filled with contents, strong peristalsis is aroused in the walls driving the fæces into the rectum and against the sphincter. By inhibition of the lower center the sphincter is relaxed, the abdominal muscles pressing upon the descending colon so that by contraction of the levator ani the fæces are excreted. The reaction of the walls of the large intestine is alkaline but the contents become acid. This is due to acid fermentation in the contents, these fermentations being indicated by the presence of gases. The fermentation depends upon the nature of the food. These fermentation changes are peculiar, being carried out in connection with the micro-organisms. By the process of absorption the contents become hard and dry. They consist of undigestible and undigested food elements with fibrous matters, cellulose connective tissue. To these must be added the productions of alimentary secretion, mucus, albumin fatty acids, salts and phosphates. The pigment of the fæces is derived from the bile pigment, being called stercobilin. If the bile is cut off the fæces become clay colored. These, together with the aromatic substances form the chief elements that constitute the fæces. The act of defecation is under the control of the special nervous centers situated in the lumbar portion of the spinal cord having sensory and motor fibers to the rectum and defecation muscles. This center is subject to the influence from the higher centers. This is evident from the fact that in comatose conditions the sphincter becomes paralyzed and the defecation is no longer under the control of the will, becoming entirely involuntary.

The nerve supply to the rectal muscles consists of motor and inhibitory fibers some from the nervus erigens through the hypogastric plexus and some from the chord of the lumbar region through the sympathetic ganglia, the inferior mesentric ganglia and the hypogastric. This, however is disputed. The paralysis of the sphincter being said by some Physiologists to be due to the in-

hibition of the lumbar center. In the rectal movements we find distinctation of the longitudinal and transverse fibers, the longitudinal movements being directed from above downward, causing the shortening of the rectum, the transverse movements traveling in the same direction, but following the other contractions, causing a narrowing of the rectum and thus pushing onward the matters within the rectum. The special changes in the large intestine are bacterial. Bacteria are usually prevented from being active by the strong acid reaction of the juice. In connection with dyspepsia we find, however, certain bacteriological developments in the case of the carbohydrates. In the small intestine the normal alkalinity of the secretion favors such bacteria. It was formerly supposed that the proteid decomposition involved such a bacterial development. But recent experiments have indicated that the contents just before passing to the large intestine are acid, if a mixed diet is used, acetic acid being formed in connection with organic substances normally about 1-10 per cent. This acid must have arisen from bacterial decomposition of the carbohydrate and not of the proteids. The formation of such acid preventing proteid putrefaction. This, however, may be changed in the case of a large proportion of proteid in the food or a deficiency in the absorption of the small intestine. In the large intestine the acidity is destroyed by alkaline reaction so that in the large intestine there may be proteid putrefaction. This putrefaction while normal may vary considerably within definite limits. The products thus produced are leucin, tryosin, indol, lactic acid, sulphuretted hydrogen, etc. Some of these are absorbed in the blood and passed to the urine, others stimulate peristaltic action.

If the stomach and intestines are removed from the body and subjected to stimulation the result will be movements of a peristaltic nature. Therefore, the entire alimentary canal has the power automatically of carrying out its own movements. If the vagus nerve is stimulated very strong peristaltic movements will result in the oesophagus, the stomach and intestines. The normal stimulation is the presence of food in the intestine. It is supposed that by stimulating the mucous membrane impulses are sent up that descend along the vagus, thus reaching the stomach and the upper part of the lower intestine by the terminals of the two vagi and to the intestines by the posterior vagus which passes through the solar plexus and the mesenteric nerves. Even after the division of both vagi, however the movements still continue. The nerves of the vagi, therefore, act as accelerator fibers to the alimentary canal. Similarly, the splanchnics act as inhibitory fibers so that by stimulating these fibers the peristalsis may be slowed and even stopped. This is explained by the fact that while the splanchnics have fibers for constriction to the intestinal blood vessels, they also have inhibitory fibers for the muscular coat and the vagi have accelerator fibers for the muscular coat, and dilator fibers for the blood vessels. In the rectum the muscular coats have different nerve connections the longitudinal coat being controlled by the nervi erigentes through the hypogastric plexus coming from the spinal cord by the anterior roots of the 2d and 3d sacral nerves. The stimulation of these contracts the longitudinal fibers of the rectum. The circular coat is regulated by nerves leaving the spinal cord by the anterior roots of the lower dorsal and first two lumbar nerves passing through the inferior mesenteric ganglia, the hypogastric nerves and the hypogastric plexus. Irritation of these fibers results in contractions of the circular coat. Thus the rectal movements are more closely connected with the central nervous system than the rest of the alimentary canal. In the small and large intestines the nervous system supplies and regulates the movements without originating them, while in the rectum the lumbar region and its fibers carry

out the rectal movements by reflex action. In diseases of the central nervous system it is here that constipation is produced, the fæcal contents accumulating in the sigmoid flexure and the colon. In addition to the stimulation produced by the food contents in the intestines the deficient oxygenation of the blood in the alimentary walls arouses peristaltic action. If the blood is interfered with by clamping the aorta peristalsis becomes violent. Hence, in death by asphyxia, the interference with respiration produces a discharge of faeces. Thus the absence of blood or deficiency of oxygenation stimulates peristalsis.

SECTION XV. 4.—Absorption.

We have found that there are different processes through which the food passes in being made soluble so as to be capable of holding in solution certain substances. In considering this question of absorption, we must regard the blood as exerting on one side of an organic membrane certain pressure while there is another fluid on the other side holding in solution certain substances. If we have two fluids that can be mixed aside from any chemical changes and if these two fluids are poured together there will be diffusion between the two fluids till there is a uniform mixture of the fluids. There will be diffusion even if the fluid that is poured on the top is lighter because part of the heavier fluid will rise to mix with the lighter fluid. It is very similar to the diffusion of gases, the difference being that liquid diffusion requires much more time. For example, it will take seven weeks to diffuse a solution of common salt with a solution of sulphate of copper poured upon it; it will take longer time to diffuse a solution of water with an overlying solution of albumin. This diffusion will be increased by a rise in temperature. If there is a separation of a porous character between the fluids, the fluids will diffuse through the pores representing a large number of fluid channels. In this case we find capillary imbibition without volmetric increase. This differs from the imbibition with change of volume as in the case of gelatin absorbing water solution the water passing into the interstitial spaces. It is in this way that albumin and starch together with connective tissue absorb fluids. If tendons are dry they will absorb more than twice their weight, cartilages and connective tissues more than three times their weight. If the membrane is dry that is brought into connection with the fluid it will be distended, the distension being greater in the water solution than in a saline solution, the water being absorbed and the salt concentrated. There is an attraction for the water in the pores, this attraction being found in the walls of these canals while the saline solution passes through the center of the pores. In this way when brought into contact with an animal membrane there are two fluid layers, (1) next to the walls consisting of water and, (2) the layer in the center containing a salt solution. If two fluids are separated by the membrane while both fluids are subject to the same pressure there will be diffusion current passing in both directions. If we have water and a solution of saline matter the water will pass more freely so that the saline solution will increase in volume. This will go on until the saline matter diffuses equally on both sides of the membrane. Glutinous substances will not pass through membranes unless very slightly, but they will attract a large proportion of the fluid from the other side of the membrane. If the glutinous matter is mixed with some substance having a crystalline structure, then the crytalloid will diffuse more slowly than if separate and the glutinous substance will diffuse much more slowly than if alone in the fluid. If a solution of albumin is mixed with salt, the salt will almost entirely diffuse out of the albumin solution In this way colloids and crystalloids may be separated by diffusion. When the diffusion of fluids takes place under the in-

fluence of pressure through animal membrane, it is called filtration. If the pores of the membrane are large, then not only the fluid but blood corpuscles and milk globlets will also pass through. Usually, however, the membrane is more delicate and then morphological elements are arrested. It is under the influence of diffusion and filtration principles that absorption takes place. Aside from the fats it was formerly supposed that absorption was a simple physical process, there being either osmosis or filtration or both combined. This has given place to the theory which takes account of the activity of the epithelial cells acting according to the living properties of animal membranes. Diffusion and osmosis, however, partially explain the processes. When two mixable fluids are separated by a membrane there is a certain diffusion through the membrane and this is called osmosis or dialysis, this diffusion taking place independently of pressure on either side. There may be as we have said, pores in the membrane but this is not necessary, as the membrane may imbibe the fluid and thus by the swelling of the membrane prepare the way for osmosis. If two different substances are separated by a membrane, diffusion takes place until equilibrium is established except in the case of certain soluble substances that are not dialyzable. Hence, Graham divides these soluble substances into two classes, (1) dialyzable, called crystalloids, and, (2) non-dialyzable, called colloids. Gelatin is the best example of the latter. In the case of the crystalloid an osmometer can measure the rapidity of the osmosis. In the case of a strong solution of sodium chloride placed in a tube with a membrane at one end and then placing the membrane in contact with distilled water the diffusion will take place both by exosmosis and endosmosis. There is much greater water diffusion than salt diffusion, hence the endosmotic equivalent is estimated by dividing the water by the salt, $\frac{\text{water}}{\text{salt}}$, this approximately representing the dialytic rate. Thus, in osmosis there must be two mixable liquids with a separating membrane. Thus, we find in the process of absortion the blood and lymph on the one side and the soluble contents of the starch and intestine on the other. The food substance we have considered in the different stages of digestion, the elements being separated in such a way as to leave the nutriment in the fluid solution, the insoluble matters becoming soluble in water and the fats being emulsified so as to be minutely divided. This prepares these substances for absorption. To this process of absorption we apply the principles of physics bearing upon diffusion. These nutritious matters are as yet outside the body in the passage through the alimentary canal. As we have seen, digestion consists of the conversion of proteids that are non diffusable into diffusable peptones by the emulsification of fats so as to prepare for the absorption process. This process takes place, (1) in connection with the alimentary canal and, (2) in connection with the other organs.

(1.) During digestion in the stomach, water, salts, sugar and peptone pass into the blood vessels in the gastric mucous membrane and are, by them, conveyed to the liver. Absorption takes place in the stomach and in the intestines, and it is especially in the small intestine, that absorption takes place in connection with the capillaries of the portal system, the absorbed substances being carried into the liver and by the lacteals into the lymphatic system, being finally transferred to the blood, and through the blood conveyed to the different tissues. Absorption that takes place directly through the blood, reaches the tissues much more quickly, as the lymph flow is so slow that it takes a long time to pass through the lymph. All nutrient matter passing through the blood, must pass through the liver by the portal circulation. These two chan-

nels representing the great fluid circulations of the body, namely, the blood and lymph.

Magendie showed that not only the lymphatic system but also the blood capillaries are engaged in absorption by showing that if the thoracic duct is ligatured and a soluble poison passes to the intestine, the death of the animal will take place as soon as normally without any ligature.

THE BLOOD.—The mucous lining of the stomach and the intestines is abundantly provided with blood vessels lying directly underneath the epithelial lining. If injections are made the capillary plexuses may be distinguished by the action of poison upon them. In the stomach the capillaries are found to form networks of irregular structure. In the small intestine the capillary plexuses exist in the form of loops changed into the villi while in the large intestine the network of capillaries is regular. These capillaries are normally filled with blood slowly moving and exerting a pressure on the internal surface, separated by the vessel walls, connective tissues and epithelium from the chyme which contains the soluble food matters. In this way, by the close connection of the blood and the solution containing certain substances we find results in the passage by absorption into the blood, of water, salts and peptones, these passing in the blood to the liver. This interchange between the blood and the lymph in the respective systems and the fluid contents of the stomach and intestines takes place on the basis of the principles of diffusion. When the blood and the lymph becomes deficient in water, salt and saccharine matters, these substances pass from the fluid in the intestines. The diffusion takes place on the basis of the difference in the substances found in the respective fluids. The rapidity of the diffusion process depends to some extent upon the motion of the fluids, the peristaltic action of the stomach and intestines keeping the digestive fluid in constant movement. It is a process of diffusion and not of filtration, subject to pressure. The blood and lymph and the intestinal fluids are in motion and hence are brought closely together, separated by the membrane. The concentration differs on the two sides of the membrane. As the blood and lymph move and as the intestinal contents move diffusion is favored. This would account for the diffusion and absorption of water, salts and sugar. This process of diffusion does not account for the absorption of fatty substances and albumin. Albumin will not readily pass through a membrane by diffusion, and only if the fluid upon one side of the membrane is rich in albumin while on the other side there is none. There is a large percentage of albumin in the blood and lymph, about 7 and 3 per cent respectively. This albuminous matter however, by the digestive processes is changed into peptones, these being readily soluble in water and thus prepared for absorption in connection with the cellular walls of the vessels. The living tissue between the soluble substances in the stomach and intestine and the blood of the capillaries consists of living cells, these cells being continuously active. Their activity implies the capacity of cellular absorption according to which the cells have the power of selecting materials. This absorption occurs to a slight extent in the mouth becoming more rapid in the stomach and is greatest in the small intestine, being less active in the large intestines.

LYMPH AND CHYLE.—The mucous lining of the small intestine is covered over with small conical projections of the mucous membrane, very numerous in the human subject being said to number four million. These form conical or cylindrical processes, projecting about 1 mm. out from the mucous lining. They consist of delicate adenoid tissue identical with the lymphatic glands. In the reticulum we find lymph corpuscles. In the center of the villus we find an open space freely connected with the retiform tissue, towards the base, the

villi becoming lacteal, the villus being abundantly supplied with blood vessels. On the internal surface of the villus there is a delicate covering of epithelium cells forming a large lymphatic cavity. At the base, there is a wall and valves constituting a lymphatic vessel. Between this vessels, called lacteal, and the membrana propria, there are fine muscular fibers, some longitudinal and some circular. When there is a rich blood supply during absorption the villus becomes hard and firm. During the process of absorption in connection with fatty substances fat particles are found in these epithelial cells or at the cell margins and the lymph spaces, in the center of the villus or in the lacteal. The fat molecules pass from the fluid in the intestines into the lacteal. Some Physiologists suppose that they are driven through the cell or between the cells by the force of peristaltic movements. It is more likely, however, that these cells by protoplasmic action absorb the fat and pass through the cells filaments, these filaments being emptied of their fatty contents by a series of sucking movements.

Definite amœboid movements have been noticed in these processes. When these fatty substances reach these filaments the contraction of the muscle fibers of the villus empties the blood out of the villus and pushes forward the substances to the large lymphatic cavity, thence to the lacteal and from thence to the neighboring villa and the lymphatic vessels. When the contraction of this filament ceases relaxation follows, the blood once more entering and producing the dilatation of the villus thus relaxing the lymph spaces. There is no regurgitation of the fluid passed into the lacteals because of the valves, and hence any substances left in the cells will be attracted into the lacteals. As soon as these lacteals become filled another action will suck the substances into the lymphatics. In this explanation no account is taken of the adenoid tissue of the villus. According to a more recent theory this tissue is very active in the absorption of fatty substances. The lymph corpuscles of the retiform tissue are supposed to project filaments between the cells, these filaments sucking in the particles so as to convey them to the cells. This is said to be proved by the fact that partially solid particles are taken into the cells. According to this theory the absorption process would go on slowly in connection with the lymph corpuscles independent of the epithelial cells. Accordingly the filaments of these epithelial cells are supposed by Schafer to be continuous with the filaments of the lymph cells connecting with the lymph tissue of the lymphatic spaces. According to this the fatty substances are first absorbed in the epithelial cells and then passed through the filaments to the lymph cells from thence to the the lymph spaces. If we suppose that the muscle fibers are active this would account for the passage of these particles in one direction from the epithelial cells to the lymph cells and on to the lymph spaces. It is not only in fat absorption that these villi are active, this would permit the free passage through the two cells from the intestine to the lymph vessels. The blood vessels and lacteals of the villi also absorb peptone and other substances. produced by the digestive process, this absorption through the blood vessels and the cells being carried on within the limits of their capacity of absorption, the surplus that cannot be thus absorbed being excreted in the fæces. In this absorption we find the activity of the mucous epithelium. If peptones are injected into the blood they will soon be excreted by the kidneys indicating that they are taken into the epithelial cells and then transferred to the lymph cells that lie beneath the epithelium cells, being considerably modified during digestion so as to assist in the cell absorption. The same change takes place in the large intestine. Voit has shown that nutritive fluids containing sugar, peptone, salts and even dissolved albumin may be absorbed in connection with the rec-

tum. Intestinal absorption takes place only within definite limits, hence, the fat is absorbed only within these limits. Voit for example, found that a dog could not absorb over 300 grams daily. Beyond this limit there is excretion of the excess undigested in the fæces. Large proportions of sugar taken into the system and subjected to digestion and absorption produced diarrhœic conditions due to excessive peristaltic action arising from the stimulation by the acid formed or by increasing the absorption in connection with the vessels. Similar diarrhœic conditions are produced by the excessive use of starchy substances producing an excessive acid fæcal matter. The lacteals mentioned in connection with the absorption of fats represent a part of the lymphatic system found in connection with the small intestine. These lacteals differ only from the general lymphatic system in the character of the fluid, chyle of a milky white color found in these lymphatics. The lymphatic system originates in minute capillary vessels, these vessels being found in the human subject all over the body wherever connective tissue is found in which are the interspaces in which the lymph is collected. The lymph capillaries are joined together into bundles passing into the smaller lymphatic vessels running through the bed of connective tissue until after passing through the larger lymphatics they are all united with the two main lymphatic ducts the thoracic duct and the right lymphatic duct opening into the junction of the subclavian and jugular vein on the left and right sides. As the lymph moves gradually from the lymph spaces to the venous circulation it is changed somewhat under the influence of the glands and the lymphatic vessels. The lymph differs in the various organs in which it arises but the chief variation is that found in the lymph arising in connection with the alimentary canal called the chyle. When digestion is not going on the fluid formed is the normal lymph. During digestion it possesses certain peculiar properties. During the digestive process, particularly if fatty substances have been taken in connection with a meal the lymph becomes milky associated with the villi and mesenteric lymphatics called the lacteals. If the food has no fat the fluid is clear and slightly yellow with no distinction from the lymph. The mesenteric lacteals unite in the formation of larger vessels which pass into the mesenteric lymphatic glands. As the vessels pass out of these glands they form the lymphatic trunk with a dilated portion called the receptaculum chyli, passing thence to the thoracic duct. Into this duct also pass lymphatics from the pelvic organs and the extremities of the body. This main thoracic duct after penetrating the diaphragm in the thoracic cavity unites with the venous system at the junction of the left subclavian and left internal jugular vein. This fluid passes into the thoracic duct where it is mixed with the normal lymph, the milky character being retained on account of the predominance of the chyle. Chyle differs from ordinary lymph in the amount of fatty substance it contains, the amount of fat varying the kind of food taken. The increase in the fatty substances is due largely to the neutral fats. The chyle from the receptaculum chyli is normally after a meal slightly alkaline with a specific gravity varying from 1018 to 1027. Examined microscopically it is found to contain in the fluid large numbers of fat cells containing minute particles very similar to the white blood corpuscles. These are called lymph corpuscles. These cells appear in the chyle after passing into the lymphatic vessels and glands. After removal from the receptaculum or the duct, chyle coagulates very much like blood, consisting of a clot and the milky serum. When the lymph is taken from the duct just before passing out of the duct into the venous circulation it is of a slight reddish hue and on coagulation is more consistent and of a reddish color. This is probably due to the mixture of chyle with red corpuscles. In the chyle we find not only the

cells but also very minute granules with characteristic amœboid movements, these forming the characteristic constituents of chyle. This minute granule division exists only in the lacteals. The chyle thus consists of lymph with the addition of a large proportion of these fat granules. The composition of the chyle is found to be in the human subject, in 100 parts, 90.5 of water and 9.5 of solid. Of this solid matter there is about 7 per cent. of albumen, 1 per cent. of fat, and 1.5 per cent. of salts and extractives with a small per cent. of fibrin. Thus, the chyle contains from 3 to 4 per cent. more of solids than normal lymph, this being due to the presence of fat. The amount of fat varies, there being often as much as 5 per cent. The increase of fat is largely due to the neutral fats. It is said that there is a larger amount of soaps, lecithin and cholesterin than in the lymph. Some of this fat exists in the globule form of various sizes, the largest amount being in the form of minute granules, these granules being characterized by the Brownian movements. These granules of fat form the molecular basis of chyle. This we find, is the condition of the fat which becomes very finely divided in the intestine preparatory to its passage into the lacteals in granular form. Thus the chyle is lymph with a large quantity of fat added. The quantity of chyle daily formed cannot be accurately estimated. It is said that an amount equal to the whole volume of the blood is passed through the duct in a day, one half of this amount from the lacteals in the alimentary canal. The amount of milky substance depends upon the fat in the food. Even in the absence of fat, water, salts sugar and peptones pass into the lymph spaces and the lacteals. These substances, however, probably are rapidly absorbed again in the blood vessels so that probably only when mixed with fats, do they pass into the lacteals of the villi and thence to the glands as chyle. Along with this chyle, the real lymph exuded from the capillaries and not absorbed in the tissue, passes into the ducts. The chyle moves from the roots of the vessels in the direction of their trunks. If poison is injected beneath the skin into the connective tissue, it rapidly passes into the lymph spaces and thence into the lymphatic circulation and the blood. By dividing the lymphatic vessels, the flow is found to be slow and continuous. The lymph movement is much slower than the blood: in the lymphatic vessels of the neck. it is estimated about 4 m m per second. The producing cause of the lymph movement is the pressure of the blood in the arteries. The flow is roots up under the influence of the pressure, the pressure being greater at the ~~kept~~ of the small vessels and less in the main trunk so that the flow is from the smaller to the larger vessels. We have seen that there are two channels opened up through which the digestive products by absorption pass to the system, the one through the capillaries and the other through the lacteals. In the first case they pass into the portal circulation by which they are conveyed to the liver. In the second case they pass through the lymphatic system, and afterwards fall into the general blood circulation. The peptones and the sugar pass readily through the capillaries of the villi into the portal system, whereas, the fat after emulsification being unable to pass through the capillaries, passes into the lacteals and thus finds its way into the lymphatic system.

The absorption takes place in the stomach and small and large intestines. 1. The stomach.—Absorption in the stomach takes place in connection with water, salts, sugar and dextrines that have been converted by salival action, also the proteoses and peptones formed under the action of pepsin. There may be also an absorption of fluids swallowed in such a condition as, for example, alcohol. Recent experiments indicate that absorption does not take place freely in the stomach. By isolation of the stomach and introducing a fistula just below the pyloric opening into the duodenum, food can be introduced into

the stomach and removed after digestion so as to observe the changes that take place. It has been found that water, when introduced alone into the stomach, is not absorbed. So soon as the water alone enters the stomach it passes to the intestine almost entirely, none or almost none being absorbed. In the case of alcohol, on the other hand, there is found free stomach absorption. The salt solutions, as for example, sodium iodide are absorbed very slowly until concentrated about 3 per cent. Absorption is found to be assisted by the use of mustard or alcohol which produces stimulation of the mucous lining.

The different forms of sugar are absorbed in the stomach, the absorption being more marked when the solutions are concentrated to the extent of 5 per cent. Absorption takes place more rapidly if mustard or alcohol is used, indicating that normally, absorption of the peptones and sugar does not take place readily. There is no digestion of fats in the stomach because emulsification must precede fat digestion and this takes place in the small intestine.

2d. The Small Intestine.—It is here that the sugar and peptones are immediately absorbed. When the partly digested food products reach the upper part of the duodenum they are acted on by the juices. These juices act very strongly on the proteids, carbohydrates and fats and as the digestive process takes considerable time, the act of digestion cannot be very complete. It is estimated that not less than two hours is occupied in the digestion in the small intestine and this may vary to six hours, much longer time being necessary before it is all passed out of the small into the large intestine. During this process conversion has taken place into soluble form being brought into contact with the mucous membrane which has a large number of villi and also folding valvulae. Experiments have proved the rapid absorption of sugar, peptones and salt solutions, it being estimated that 85 to 90 per cent of the proteid matter is absorbed during the passage through the small intestine.

Water and Salts are also freely absorbed, a large part of the water and salts being used in connection with secretion and the maintenance of the fluid condition of the chyme.

3d. The Large Intestine.—Absorption takes place freely in the large intestine The passage of the contents takes place very slowly from 10 to 12 hours being occupied in the passage through the intestine during which time they are changed from the semi-fluid condition to the solid consistency as faeces. When entering the large intestine there is usually a small proportion of sugar, proteids and fats. Part of these is decomposed in connection with bacterial action, part of it being absorbed even before the commencement of decomposition. The absorbing power of the large intestine is indicated by the use of enemata, large quantities of distilled water and other fluids being readily and rapidly absorbed. Even soluble proteids may be readily absorbed in connection with the rectum although no ferment is known to exist that can act upon these. In the same way fats and sugar may be absorbed by injection.

Proteid absorption.—There is absorption of the proteids in the stomach and the small and large intestines, more particularly in the small intestine. The final products of the digestive action of the ferments are peptones and parapeptones. By the action of the trypsin there are produced the amido-acids, tryosin and leucin. The proteolytic action, therefore, presents the soluble proteose, peptone and triptone which are easily absorbed. Proteids may be absorbed, however, in other ways. For example, proteid dissolved, such as egg or muscle in solution injected into the rectum will be readily absorbed without any digestive action. In the peptic digestion syntonin is formed and in all probability it is directly absorbed as such, but the large proportion of the converted substances are changed to

peptone. This absorption takes place not simply by dialysis as the albumin of egg that is non-dialyzable becomes readily absorbed in the intestine. Its rapidity also makes it impossible that the process should be simply dialysis. In some way there is activity of the epithelial cells in the absorption of these peptones. They are then passed directly to the blood capillaries, for if the lymphatic duct is ligatured peptone absorption goes on normally. Although the absorption takes place directly to the blood, there does not seem to be any of these substances in the blood when examined. If they are injected into the blood they act as obstacles to the blood circulation and impurities resulting in certain cases in death. If thus introduced directly into the blood they pass from the kidneys without any assimilation. This seems to indicate that in passing through the cells, these peptones are changed in some way so as to form practically new substances said to be serum albumin. If this is true the process is one of dehydration. If a loop of the intestine is taken out of the body and artificial digestion is kept up in connection with the mesenteric arteries the loop will live for a time. If peptone is placed in the loop a considerable proportion will disappear but will not be found in the circulation that is kept up in the loop. The peptone does not disappear in the blood, indicating that the peptone is changed before passing from the cells to the blood. By the absorption of proteids, the kidney excretion of urea is increased. If the thoracic duct is ligatured to prevent the chyle from passing to the blood and if the animal is fed on proteid the urea increase will still be observed. This indicates that the soluble proteids do not pass into the chyle but into the blood.

SUGAR ABSORPTION.—The absorption of the carbohydrates takes place largely in the form of sugar and dextrine. By the intestinal juice starch is changed to maltose and dextrin and by the inverting into the dextrose. Cane sugar is transformed to dextrose and laevulose. Milk sugar is converted to dextrose and galactose. Thus in the form of dextrose or laevulose the absorption takes place. The sugar found in the blood is the dextrose form. In this form oxidation takes place readily in the tissues. If cane sugar is injected into the blood it will not be assimilated but will be excreted in the urine, while dextrose so injected will disappear. The absorption power of sugar differs, the absorption not being directly proportional to the diffusibility. Absorption increases with the concentration until the maximum of 5 per cent is reached. This indicates that it does not take place by a simple diffusion. Hence, it is supposed to be similar to proteid absorption depending on the activity of the epithelial cells, passing directly from the cells into the blood. If there is a large quantity of sugar in solution in a large quantity of water, absorption takes place also into the chyle, the water passing to the lacteals and carrying the sugar with it. In the passage into the blood from the cells there is a change, the maltose which forms the largest proportion of sugar in the chyme, being changed to dextrose or the blood form of sugar.

FAT ABSORPTION.—Fats are absorbed largely in solid form in the condition of emulsification, so that the process of absorption is not that of osmosis. The epithelial cells of the villi in the small intestine are especially active in connection with fat absorption. The fat globlets are drawn into the cells and passed through the cell substance, passing then through the cells into the villi-substance. There is a large lymph capillary terminating at the top of the villus, the villus substance lying between the epithelium and the lacteal. These fat particles pass from the epithelium cells to the lacteal and thence to the lymphatic system. Thus, the fat passes largely if

not altogether into the lacteal system, the adenoid tissue containing a number of minute lymph canals in connection with the lacteals, the fluid exuded from the blood capillaries keeping up a constant stream of lymph through the villus to the lacteal. By estimating the amount of fat taken in a meal and the amount found in the faeces as well as the amount found in the thoracic duct it is estimated that 60 parts out of every 100 parts of fat which leave the alimentary canal pass into the thoracic duct and into the venous system. . The question is, what becomes of the balance? Some say that it passes into the portal circulation, as there is a quantity of fat found in the portal blood during digestion. A large proportion of the fat however passes through the lacteals.

WATER AND SALT ABSORPTION:—Only a very slight absorption of water takes place in the stomach. Along with the peptones, sugar and salts there is an absorption of water. In the small intestine there is a free absorption of water and salts. Heidenhain has proved that the absorption of water and salts in the small intestine takes place in connection with the blood vessels and not through the lacteals unless where a large quantity is taken, when the lacteals absorb some of it. In the large intestine the water is absorbed in connection with the blood, the epithelial cells attracting the water into them and then giving them off into the blood. The fats are emulsified by the bile and the pancreatic juice in the intestine, the soap formed, aiding in the emulsification. The emulsified fat enters into the columnar cells in the villi. The margin of the cell is thought to be active in the entrance of the fat, the leucocyte being active possibly in amoeboid movements. The bile is supposed to assist the passage of the fat particles by bringing the fat more closely together and acting upon the cell substance. Inside the columnar cells these fat particles can be seen in the living cells, the particles occupying the spaces in the protoplasm. Some suppose that the fat enters in very minute particles and then that these are joined together into larger globules.

Out of the columnar cells the fat passes to the spaces in the reticular tissue, filling up the reticular spaces which are vacant, many of these spaces being filled by the migratory leucocytes. As soon as the fat passes through the cell base it enters into these reticular spaces, the passage taking place probably by amœboid movements. From the reticular space it passes to the lacteal cavity, part of the fat being changed in its passage into the minute division known as the molecular base. It ceases to be emulsified fat at this point and becomes chyle. In this lacteal root we find not only fat but also the proteid that constitutes the chyle, this proteid and other substances being derived from the blood capillaries. In the reticular spaces are found migratory leucocytes, some of them passing between the cells, entering into the intestine. Some pass into the villus cavity. From this some have concluded that the leucocytes play, an important part in fat absorption, taking up the fat and then moving back with the fat absorbed so as to carry it to the lacteals and the lymphatics. This, however, cannot be carried on to any great extent, as the number of leucocytes is too small to admit of their carrying on all the fat absorption. The base of the lacteal cavity opens into the lymphatic vessel in which the lymph flow takes place. By the peristaltic action the lymphatic vessel is emptied of its lymph and the lacteal is also emptied of the chyle. The muscle fibers of the villus also act as a compressing force to empty the lymphatics and the lacteal vessels. These fibers are all running in one direction, parallel to the vertical axis of the villus. By contraction the villus is shortened so as to

empty the lacteal. By relaxing the villus is lengthened and the lacteal opens to be again filled. According to others, the contraction of the fibers and the shortening of the villus makes the villus broader, and thus permits the lacteal to be filled; whereas, the relaxation lengthens the villus and narrows it, thus emptying the lacteal. During the digestive process these contractions and relaxations are going on so that there is a constant process of emptying and filling the lacteals. By the contraction of these muscle fibers in the villus compression is brought to bear on the columnar cells. While on relaxation of the muscular fibers the cells will also relax, these muscular contractions and relaxations assisting in the passage of materials from the intestine into the cells. In the case of the substances which as distinguished from the fats are, diffusable, including water, salts and peptones, there is absorption into the blood vessels rather than into the lacteals. The capillary blood vessels are lying immediately beneath the membrane. During the digestive process the blood vessels are filled. There is a transudation of fluid from these vessels into the reticular cavity and the lacteals and a similar transudation from the external and the internal surfaces of these capillaries. Passing through the epithelial cells of the reticular cavity, the diffusable substances are diffused through the vessel walls, the diffusion taking place in two stages.

1st. From the intestine to the spaces passing through the epithelium cells; and 2d, from the lymph spaces to the capillaries. These substances including peptones pass slowly, the diffusion taking place on the principles of physical osmosis subject to the Physiological structure of the membrane separating the fluids. The rapidity of this diffusion can be determined by placing solutions of these substances in the intestinal loop and carefully watching the process of diffusion. The diffusion will take place at different rates depending on the substances and the condition of the membrane.

2. ABSORPTION BY MEANS OF THE OTHER ORGANS OF THE BODY.

Absorption takes place in connection with (a) the skin. Absorption by the skin takes place in connection with gases and to some extent fluids and semi-fluids and solids. By the absorption of gases like sulphuretted hydrogen through the skin after every other passage is closed, the animal may be poisoned. In the case of liquids it seems almost impossible that fluids should be able to make their way through the epidermis and the fatty coating of the outer surface. In addition to the strong coating the pressure is always very strong from the internal surface. This, however, does not prevent the demonstration of the passage of water and even of fatty and oily matter through these surfaces, particularly if associated with mechanical stimulation. Mercurial solutions by external massage may be made to enter freely into the tissues from which diffusion will take place. These substances pass through and into the ducts of the sebaceous layer upon the surface, being absorbed into the vessels found in connection with these glands. It is also possible for certain solid substances in solution to be absorbed in this way, as in the case of saline substances. Any of the mucous surfaces to which such substances are applied will freely absorb them, as the rectum and urethra. The vapor arising from a bath, as for example, in iodine of potassium baths may be absorbed in this way, the substances appearing very soon in the urine. Alcohol, ether and turpentine may also be feely absorbed by rubbing on the skin.

(b) SEROUS ABSORPTION:—The Serous surfaces represent a large tissue or lymph spaces and their stomata communicate with the lymphatic ves-

sels. During inflammatory stages there is an accumulation of fluid in connection with these serous surfaces such as the peritoneum or pleura, the fluids being absorbed. The absorption takes place readily in connection with the openings at the margins of the lining cells. The fluid that is found in connection with these serous membranes is very similar to the lymph. It is alkaline in reaction, containing about 4 or 5 per cent of solid matter.

(c) PULMONARY ABSORPTION:—In the lining membrane of the air vescicles the absorption of gases takes place very readily. Also fluids are absorbed, although not so freely. For example, water passing into the air passages and the air cells may be absorbed without any detriment if not excessive in quantities. In the case of persons engaged in certain occupations small particles of foreign substances, for example, steel fillings may be found in the lung tissues having been breathed into the lungs and absorbed by or in connection with the delicate cells lining the surfaces of the air cells.

(d) THE TISSUES IN GENERAL:—From the blood nutrient matters are constantly passing out into the tissues and the amount of this matter is always in excess of the tissue requirements. In addition the injection of solutions underneath the skin brings these solutions into close relation with the connective tissue, these solutions being absorbed and passed into the system. This fact lies at the basis of the hypodermic method of subcutaneous injection of medicines. In addition the constant activity of the tissue corpuscles leads to the formation of waste matters and these together with the excess of nutrient matters lie in the tissue spaces from which they are carried off partly by the blood vessels and partly by a special set of vessels communicating with the tissue spaces, the lymphatic capillaries by which they are carried into the general lymphatic circulation.

CHAPTER VI.—SECRETION AND EXCRETION.

SECTION I.--Introductory.

1. SECRETION.—The term secretion is applied to the fluid products of glands. The term gland is used to designate a number of structures that differ in organization. The gland consists of a structure composed of gland cells secreting the fluid that is discharged upon a mucous epithelial surface or in connection with closed epithelial surfaces found in connection with the blood and the lymph cavities. Secretions are either external or internal, the external referring to secretions discharged upon a free epithelial surface like the skin or the mucous lining; the internal secretion is found in connection with the closed epithelial surfaces of such glands as the liver, pancreas, etc. This does not mean that other organs, even without epithelial surface, may not secrete substances in connection with the blood. For example, the muscles may give to the blood such substances as are analogous to secretions. In the case of external secretion it always takes place upon a free surface of epithelium resting upon a membranous basement. the other side of the membrane being freely supplied with blood capillaries and lymph spaces. The secretion always takes place in connection with the blood, the discharge taking place in the epithelial surface so as to communicate with the exterior. Of this kind is the membranous surface of the alimentary canal. Wherever we find the membrane pouched or formed into sacs with a definite bore we find the primary gland either tubular or sacular. In the case of the compound gland we find the complexity of the insolutions with branching side portions either in the common tubular or saccular form

according as the terminal parts end in the tubular or saccular form. In these compound glands it is only in the terminal parts that secretion takes place, these terminals being alveoli or acini, the communicating parts being called the ducts, the lining membrane of these ducts having no secretory action. The gland secretions are as different as the structures in which the secretion takes place. In general these secretions other than the reproductive secretions are fluid or semifluid, being composed of water, salts and other organic substances. The organic elements differ in the various glands repsenting the elements which are peculiar to the gland. being formed in connection with gland activity. In other cases the organic elements are found in the blood, the glands simply separating these elements from the blood so as to be eliminated, as the urea of urine. These last are the excretions of the body, excretion being the process of the elimination of waste matters from the body such as would be disadvantageous to the system if retained. Thus excretion does not refer to any secretion taken as a whole, some elements being derived from different secretions as in the case of urine of which urea and uric acid are formed in some of the organs, the water and salts being taken from the blood. Similarly, the bile represents an excretion carrying away some waste matters while it is also a secretion containing valuable elements in the digestive action. Excretion, therefore, represents the carrying off of the waste of the body organs or certain parts of some of the secretions which constitute the excretions.

No general theory of secretion can be formulated. because the formation of secretion varies in the different glands so that each gland has its own peculiar form of secretion. Formerly it was supposed by Physiologists that secretion was accomplished by filtration, diffusion and imbibition, the membrane beneath the epithelium being supposed to form with the epithelium, the membrane through which diffusion took place in connection with the blood and lymph. The differences in the secretions depends upon the structural difference and the chemical action of the membrane. In this case the epithelial cells were supposed to be inactive and the metabolism of the cells was not supposed to be of importance in connection with the secretion. In modern times, emphasis is laid upon the living membrane, the gland itself being used in the process of secretion; the epithelial cells being active in the secretory process. This is evident from the fact that on examination under the microscope the secretion is found to contain parts of cellular substances. In some cases the cells being broken down to form the secretion, as in the case of the sebaceous glands. In the case of the stomach glands there is an expulsion of part of the mucous from the cells to form the secretion.

In the mammary glands, the cell substance is broken up and in other glands the secretion of the substances take place in the cells in the form of granules which, when the fluid is passed through the cells from the blood or lymph becomer dissolved. The substance of the gland cells passes into the secretion in this way and represents the metabolic process of the cell substance. The variations in the secretions are easily explained on this basis as depending upon the metabolism of the different gland cells. In addition to this the existence of nerves connects with those gland cells. the stimulation of which produces secretion is a confirmatory proof of this theory of the cell activity.

Ludwig first pointed out that stimulation of the chorda tympani increased the secretion of the submaxillary gland. Similar nerve fibers have been found in connection with the sweat glands, stomach glands, pancre-

atic glands and the lachrymal glands. These secretory fibers are found to be of two kinds, one regulating the secretion of the organic and another the inorganic elements. By microscopic examination these two kinds of fibers are found to end around the cells in plexuses. indicating the direct connection of the fibers with the cells. Changes of temperature in the glands are also noticeable in connection with the formation of the secretion indicating the existence of metabolic processes, the heat changes, marking the activity of the glands. Although the granular structure is favorable to the process of osmosis, this does not seem sufficient to account for the secretion of salts and other substances. In this case the cells in connection with which are found two fibers, one regulating the production of the organic and the other the inorganic elements, play a very important part, as these two fibers terminate around the cells. How the action takes place it is impossible to state. It is sufficient to indicate the fact that some cell metabolism takes place under the influence of nerve impulses, conveyed to the cells by the nerve fibers. In the formation of water in connection with the secretions, it was formerly supposed that by diffusion and filtration, it was passed from the blood and the lymph. It was supposed that the greater blood pressure accounted for the osmosis, the water and salts in solution in the water, being the products of transudation. To this there is the objection that in the case of living membrane there is not a free diffusion, even when the pressure is greater on the one side of the membrane. The lung of a newly killed frog was found by Santessen, not to permit of the free filtration of liquid from its cavity, even under great pressure; whereas, the same lung when dead, freely filtered the fluid under the same pressure. In addition to this, the secretion in the gland does not increase with an increase of blood pressure, proportionate to the increase of pressure. While, therefore, these processes of filtration and osmosis take place in connection with the formation of the secretions, these physical processes seem to be only a part of the process associated with the formation of the secretion.

Heidenhain distinguished two kinds of glands, the mucous and the serous, the difference being made on the basis of the physiological structure of the glands, and also upon the nature of the secretion. The secretion of the serous glands is limpid, containing a large proportion of water together with a small quantity of albumin, salts and the ferments. The secretion of the mucous glands is viscous and thready, on account of the amount of mucin present in the fluid. The parotid gland in the human subject is an example of the serous gland and the submaxillary in the human subject with the sublingual the orbital and some of the mucous glands of the mouth and oesophagus are examples of the mucous gland. In serous glands the cells are small and abundantly filled with granular material. In the mucous glands the cells are larger and freer from granular matter. The small goblet cells in the intestinal epithelium are examples of the mucous cells. In the fresh glands the granules are not distinct. The use of chemical reagents will make them distinct although they are not so closely packed together as in the serous glands. In the submaxillary gland both kinds of cells are found although it is called a mucous gland because of the large proportion of mucin in the secretion. Similarly the parotid gland contains cells that are mucous in character. The distinction is more definite and well marked in distinguishing between two kinds of cells, the serous and the mucous. The epithelium is of the columnar type, in the midst of these cells, being found the mucous cells. Primarily also columnar they become changed chemically in the production of mucin. producing a swollen condition at the free end. This

mucin arises from the protoplasm of the cells so that the neucleus of the cells becomes fixed at the base of the cell. The mucin thus formed at the open extremity becomes gradually pushed outward until it escapes into the intestinal cavity so that the empty cell is left with the neucleus toward the base. According to some any of the columnar cells may perform this function of forming mucin internally, after expelling the mucin the normal condition of the cell being restored, Others think that they are distinct cells entirely different from the ordinary epithelial cells. Whichever view is correct the mucin is the actual product of cell metabolism, this metabolism taking place in some way that is as yet unknown as it is not known that there are any secretory fibers in connection with goblet cells.

SECTION II. The Salivary Glands.

These glands in the human subject are found in three pairs, the parotid, the sublingual and the submaxillary. Besides these we find a number of small glands that are embedded in the mucous lining of the mouth and tongue. These glandular secretions form the saliva. The parotid gland in the dog has nerve connections in the cerebro-spinal system, from the fibers originating in the glosso pharyngeal, passing into the tympanic nerve and thence to the small superficial petrosal nerve and the otic ganglion in the oval foramen supplying the ear. From this ganglion they pass through the inferior maxillary division of the 5th cranial to the parotid gland. The cervical sympathetic also sends branch fibers into the coatings of the blood vessels of the parotid gland. The submaxillary and the sublingual glands receive their nerve connections in the cerebro-spinal system from the facial nerve through the chord tympani, joining the lingual nerve after leaving the tympanic cavity. After going along the lingual a short distance the secretory fibers branch off and enter the lingual along the ducts, passing through the submaxillary ganglion at the point where these fibers leave the lingual. The sublingual fibers connect with the cells in this ganglion while the submaxillary fibers connect with the nerve cells in the gland hilum. The sympathetic system also sends fibers that pass from the superior cervical ganglion, these fibers connecting with the blood vessel coatings. These salivary glands are compound tubular glands, the secretory parts being tubes, although these tubular parts are irregularly formed. The parotid gland is a serous gland although some of the cells are mucous, the epithelial cells contain a large number of granules, the membrane consists of flat connective tissue cells, the inter-spaces being occupied by fine membrane. The submaxillary and sublingual glands in the human subject consist of mucous and serous cells, the mucous cells being more numerous. The result is that the the sublingual and the submaxillary secretion is viscid as compared with the parotid. In the mucous glands there is a special kind of cell called the crescent cells between the mucous cell and the membrane away from the surface of the gland tube. Heidenhain believes that these cells when the mucous cells become disintegrated take their place while others think that the crescent cells represent an inactive condition of the mucous cells or simply the basement structure of the mucous cells. The cells are arranged around the bore of the gland tubule, in the case of the serous cells the bore being continued in the interspaces between the cells representing minute capillary spaces. In the mucous glands these capillary spaces are found in connection with the crescent cells which seems to indicate that these crescent cells are functionally active. The secretory fibers from the

chorda tympani in connection with the sublingual and submaxillary glands terminate in the ganglion cells of the gland, the secretory fibers proper passing from these ganglias to the secretory cells. forming a terminal net work in close contact with the cells. The saliva represents the mixture of this gland secretion and also the secretions of the smaller glands of the mouth and tongue. It is a colorless slightly viscid fluid, alkaline in reaction with a specific gravity of 1,003. In it are found epithelial cells and salivary corpuscles. It contains mucin and the enzyme ptyalin with traces of albumin. salts and potassium sulphocyanide. Albumin is the chief organic element found in it, the mucin causing it to be thready and viscid. Mucin belongs to the glyco-proteids being a proteid combined with a carbohydrate. There is a large quantity of gas, CO_2 present in the fresh saliva. Pfluger having found 65 per cent representing 42 per cent of carbohydrates and 8 per cent of N and .6 per cent of O. In the parotid secretion we find no mucin, a larger percentage of gases, for example CO_2, 66 per cent; N. 3.5 per cent and O 1.5 per cent. Ludwig discovered that by stimulating the chorda tympani, the submaxillary gland gave out an increased flow of saliva. It was thus found that a double nerve supply went to the glands from the cerebro spinal and sympathetic system. In addition to the secretory fibers it was found that vaso motor fibers are also bound up in the same nerves, cerebro spinal nerves representing the dilators, and the sympathetics the constrictor fibers and producing respectively a dilatation and a constriction of the blood vessels and a consequent increase and decrease of the blood flow. By weak stimulation of the chorda tympani gland secretion takes place, the secretion being limpid with a small per cent, 1 or 2 per cent of solids, flowing freely and abundantly. There is an increase in the blood flow producing reddening of the gland, distension of the veins, the blood being of a very red color. By the stimulation of the sympathetics the secretion is diminished, the flow being slow and the fluid viscid with 6 or 7 per cent of solid matter. The gland becomes pale owing to the diminished blood flow. This suggests that the secretion is intimately connected with the vaso-motor action, the vaso-motor action regulating the amount of the fluid flow. This, however, represents an imperfect statement of the causes of the secretion. According to the older view the specific function of the gland was to permit certain elements from the blood to pass through the cells to the ducts and to prevent the passage of others. It is known, however, that the elements of the saliva, especially the mucin are not found in the blood ready made.

Ludwig proved by the use of the manometer that under the stimulation of the chorda tympani the pressure in the submaxillary gland duct may be greater than the blood pressure, and that if the blood supply is cut off from the gland the secretion will increase upon the stimulation of the chorda. By injecting atropin into the gland the stimulation of the chorda will produce no secretion, although the blood supply is increased. In this case it is supposed that the secretory fibers are paralyzed while the dilator fibers remain active. In the case of the parotid gland if the cerebro spinal fibers are stimulated, there will be a very free watery saliva, while the stimulation of the sympathetic fibers, if the tympanic nerve is divided will give no secretion, although a change takes place in connection with the gland cells which when the cerebro-spinal fibers are stimulated, yield a viscid secretion indicating that a change has taken place in the cell by the increase of the stimulation applied to the chorda, the water and salts will increase in proportion until a certain limit is reached beyond which there will be no increase

A similar increase in organic matter takes place if the gland has been previously resting, but this very soon stops, the continued stimulation producing a decrease after this point rather than an increase in the solid matter. If the gland, however, has been continually working although the water and salts increase, the organic matter will not increase upon stimulation. These experiments led Heidenhain to distinguish between the production of water and salts and the production of organic matters, a distinction he has explained by his theory of the secretory and trophic fibers. According to this theory there are two sets of fibers to the salivary glands, the one regulating the water and salt supply called the secretory and the other producing organic matters in connection with cell metabolism, and hence, called trophic. In the case of the parotid gland, the sympathetic fibers are trophic or almost all trophic, while the cerebro-spinal fibers represent both the trophic and secretory. In the submaxillary gland, the sympathetic fibers are trophic or almost all trophic while the cerebro spinal are secretory or prevailingly so. There may be variations in the individual fibers in the case of particular animals. This may be due to the fact that there is a combination of the two kinds of fibers in the one system. The trophic fibers are supposed to act by setting up metabolic processes in the cells resulting in the formation of certain substances like mucin. That these changes do take place has been demonstrated by microscopic examination. These processes represent the breaking up of complex matters and the formation of simpler substances found in the secretion. Side by side with the katabolism we find anabolic changes forming new materials from the blood supplies furnished to the cells, although the katabolic changes are more prominent, being under the influence of the trophic fibers. The action of the secretory fibers is obscure although it is supposed that the flow of water is regulated by the gland activity, this gland activity attracting to the gland cell the water from the blood, the water being absorbed during the resting condition of the gland from the membrane which collects its fluid, the lymph in turn being supplied from the blood. As the water in the cell increases there is a point reached when the equilibrium is established after which no more water is passed. By the action of the secretory fibers the process of filtration is materially assisted, the water passing from the cell into the lumen of the tubule. Ranvier has pointed out that during secretion there is the formation of minute vacua in the substance of the cell, these being filled with water. During the activity of the glands there are very marked changes in the cells both of the mucous and serous glands. In the parotid gland during rest the cells are large, solidly filled with granules, the nucleus being small.

After the stimulation of the sympathetics the cells become smaller, the granules more closely compacted, and the neuclei more regular and rounded, the granules being arranged in two layers, the outer and inner, the latter being more dense. By increased stimulation the granules are decreased and are collected around the margin, the increase of stimulation throwing out the substances from the cell and the cell becoming smaller in size. In this way the granules are utilized in the formation of organic matters. It is supposed that the ptyalin or that from which it is formed, is contained in the granules during the resting condition, the ptyalin formation taking place during activity. During activity these granules change and are removed from the cells and new substances are built up out of the matters derived from the blood and lymph, representing the nongranular matter. During the resting of the cell there is formed new granular matter. In the mucous

cells we find during rest the cells large and clear with flat neuclei toward the cell base. During activity the neuclei are rounded and approach the center of the cell, the cells being smaller. By prolonged activity the cells become still smaller, some of them being broken up and their places being taken by the crescent cells lying underneath. In these mucous cells large numbers of granules appear from 100 to 200 in every cell, the granules being composed of mucin or something from which mucin is formed. As the secretion goes on these mucous cells like the serous cells become smaller, the granules being used in the formation of the secretion. There are thus two processes in the act of secretion, the process of water diffusion from the blood including salts and the production of certain constituents of the saliva in connection with cell metabolism.

These constituents when formed in the cells are washed out into the ducts by the water from the blood. If small quantities of atropin are injected into the blood or into the duct of the gland, the activity of the cerebro-spinal fibers, is suspended on account of the paralysis of the fiber endings in the cell. It does not seem to affect the cell as the stimulation of the sympathetics produces secretion. On the other hand, if pilocarpin is injected into the blood, or the gland ducts the secretory fiber endings stimulated and there is produced a continuous secretion. Nicotin seems to have a different effect, stopping the action of the secretory fibers by producing paralysis of the cells in the ganglia, through which the fibers pass to the gland cells. If the chorda tympani is divided after a few days, the secretion of the submaxillary glands begins slowly and continues slowly for some time until the gland becomes atrophied. This is called the paralytic secretion. If the chorda is divided on the one side there is a secretion on both sides, the secretion on the side opposite to the one divided, being called anti-paralytic by Langley. He explains the phenomena as due to the excitation of the secretion center in the medulla, being so largely increased as to produce by the excessively venous blood the continuous secretion.

Bradford, however, explains it more satisfactorily by saying that the anabolic fibers of the gland are inhibitory of the katabolism of the cells so that if these fibers are divided, the gland cell is handed over to the continuous action of the secretory fibers, producing a continuous secretion until the gland is atrophied. Normally salival flow is the result of stimulation of the sensory fibers, the glosso-pharyngeal and lingual nerves, of the mucous membrane of the tongue, the impulse thus arising being sent to the center and transmitted by the efferent fibers along the chorda tympani or the sympathetic system to the glands by reflex action. If the chorda is divided the reflex is cut off, even if the sympathetics are undivided. As the flow of saliva is a reflex action there would naturally be a reflex center associated with the flow, and it has been located in the medulla not far from the vasomotor center. If the medulla is destroyed no salival flow can be produced by stimulation. The direct irritation of the medulla will produce a flow. This center may be stimulated through the vagi, the sciatic or the splanchnic nerves, as well as through the psychic centers as in the case of nausea, preceding vomiting when there is a flow of saliva. In the same way the center may be inhibited under the influence of the higher centers as in the case of emotion, fear or fright.

SECTION III. Pancreatic Secretion.

The pancreas in the human subject is found behind the stomach in the abdominal cavity. It is found to be a long narrow gland, its upper end

being in contact with the duodenum, and its lower end resting upon the spleen. The main duct opens into the duodenum along with the bile duct below the pyloric orifice. Sometimes there is a small duct farther down. The pancreas is one of the compound tubular glands, the alveolar cells being serous, the outer part of the cell being composed of non-granular substances, the inner part toward the cavity being granular. In addition to the regular cells there are also a number of small and clear cells irregularly shaped, supposed by some to be imperfect secretory cells and by others a different kind of secretory cell taking part regularly in the secretory process. The tubular cavity of the cell is continuous with the capillaries which lie between the cells, the capillaries branching out into the cell substance. The pancreatic secretion is clear and alkaline in reaction. Its character depends on the time when it is taken and also on the animal. Its alkaline reaction is due to the presence of the sodium carbonate, varying from .2 to .5 per cent. The pancreatic secretion seems to depend somewhat on the stomach digestion, the beginning of the secretion being connected with the beginning of digestion and therefore a reflex action. There are distinct secretory fibers just as in the case of the salivary glands. The stimulation of either the sympathetic or the pneumogastric increases the pancreatic flow after a period of latent rest. The same distinction of the fibers is found in connection with the secretion, the secretory fibers predominating in the pneumogastric and the trophic fibers in the sympathetics. By the stimulation of the medulla the flow of pancreatic juice is increased, changing the contents of the organic portion. Some previous experiments give different results, probably on account of the changes in the blood supply, as the constriction of the blood vessels hinders the action of the secretory fibers. If the sympathetics are stimulated there is usually no effect upon the secretion because at the same time there is constriction of the vaso-constrictor fibers. If the sympathetic nerve has been previously cut so as to produce degeneration of the vaso-constrictors, the application of stimulation will produce, after a period of rest, a secretion of the pancreatic juice.

Heidenhain's theory of secretory and trophic fibers has been applied to the pancreas, the sympathetics containing the trophic fibers and the vagi the secretory fibers. It is difficult to explain the period of latent stimulation which is long, between the application of stimulation and the secretion of the fluid. It has been suggested that this is due to the presence of inhibitory fibers which check the action of the secretory fibers. The cell changes in the gland are very similar to those of the salivary glands. By subjecting the pancreas of the rabbit to microscopic examination the pancreas can be examined while alive, both active and inactive. During inactivity the cells become indistinct, each cell being filled with minute granules covering the nucleus and leaving exposed only a small zone next to the basement. When active the cells are smaller and more distinct, the granules being fewer in number. In the case of the fresh gland which has been inactive the cells are full of granular matter except at the base where there is a narrow zone non-granular. In the case of a pancreas that has been active the granular portion is much smaller and the non granular part much larger. The cell is found to be much smaller during activity, the granular matter being used up in connection with the secretion. When the secretion has been completed the cell returns to its normal resting condition, new granular matter being formed, the new granules filling up the whole cell except a small portion at the basal end. When the gland is not active the separate cells cannot be clearly distinguished from one another, the only distinction

in the gland being between the clear and dark zone. While active the cells of the gland become distinctly marked, the part of the organic matter of the secretion being formed in connection with the granular matter, the granules being formed inside the cell. This seems to imply that during rest the cell is forming by metabolism certain products out of its own substance, certain substances which fill the cell so that during secretion these are discharged from the cell and unite with the water and other substances to form the secretion. It is supposed that the pancreatic ferments are taken from the granules of the cells, the granules containing the zymogen from which the ferment is formed. If the gland is taken from a dog that has been fasting and the gland is prepared with glycerine there is almost no ferment found in it. If the gland is kept heated about 35° C and then after a day is prepared in glycerine the extract of glycerine will exhibit strong fermentive action. This indicates that the substance out of which the ferment is formed is contained in the granules, so that corresponding with the three ferments we have three ferment formers. The pancreatic flow is closely connected with the digestive action. As soon as the food enters the stomach there is a flow of the secretion which increases until it reaches its maximum about the second hour after a meal. Afterward it gradually diminishes until the fourth or fifth hour and then increases again until the 9th or 10th hour after which it gradually diminishes. These estimates have been made in connection with the dog and would require modification in application to the human subject, depending chiefly on the variation in the time of meals. In human beings and lower animals the beginning of the secretion seems to be almost simultaneous with the beginning of digestion in the stomach. This indicates that pancreatic secretion is aroused by the stimulation upon the mucous membrane of the stomach, the action taking place reflexly. In some animals it has been found that by the use of condiments like pepper, or mustard introduced into the stomach and intestine the pancreatic secretion is greatly increased. It has been found that acids have the same effect while alkalies have the opposite effect. The acidity of the gastric juice is probably the chief stimulant, the flow of the gastric juice originating the impulses that excite the pancreas. This action probably takes place by stimulation of the sensory fibers of the mucous membrane. The nerves of the pancreas come from the solar plexus of the splanchnic sympathetics, some of them coming primarily from the right vagus. If the medulla is stimulated the resting gland will secrete fluid indicating that it is a reflex action, and this takes place, even though the vagi are divided so that the efferent impulses must pass some other way than through the vagi. If the gland is active secretion will be arrested by the stimulation of the central end of the vagus. The same effect follows from the stimulation of the sciatic indicating the inhibition of the center in the medulla. It is claimed by some that even after cutting off all nerve connection the gland will continue to secrete but this has not been proved. Thus, the action of the pancreas during secretion is very much analogous to the action of the salival glands.

SECTION IV.--Gastric Secretion.

The gastric glands are simple tubular glands which possess no system of ducts such as are found in the compound glands. There is a large opening in each gland, the opening being lined with epithelium of the columnar type. The longer part is narrower and forms the secreting portion, being lined with cells of the cuboidal type. The pyloric glands differ from the fundic glands,

having only one kind of secreting cell while the fundic glands have two kinds of cells. In the fundic glands the lining is of cylindrical epithelial cells which Heidenhain calls the principal cells. It is in these cells that pepsin is formed. There are also oval cells lying close to the basement membrane and not extending as far as the cavity of the gland. These are called marginal cells, sometimes oxyntic cells because of the formation of the acid of the gastric juice in these cells. These cells are spoken of as undeveloped cells of the principal type. It seems that they are cells of a peculiar kind, having a special function of their own. In these cells it is found that there exist often a number of nuclei, as many as five or six. In the cells are also found vacua which develop, after the beginning of digestion becoming larger, and then after becoming smaller gradually disappear. This seems to be connected with the formation of the secretion. The duct of the gastric gland is not continuous throughout the length of the gland, the central cavity sending off branch cavities to the marginal cells forming a meshwork around the cells. The principal cells have direct communication with the central cavity, the marginal cells being communicated with by a series of capillary branches. This indicates the fact that the marginal cells are distinct from the principal cells. In the secretion of the glands upon the mucous membrane we find the gland secretion mixed with mucin derived from the cells upon the surface of the mucous membrane. In addition to the mucous, the water and the salts, there is the hydrochloric acid and the ferments pepsin and rennin. According to Heidenhain the secretion of pepsin takes place in the pyloric end. The pyloric end was, by him, made in a seperate sac and bound to the abdominal walls so as to be separated from the rest of the stomach, so that the secretion of the pyloric end was obtained free from the secretion of any other part of the gland. This forms the negative proof which Heidenhain finds for the secretion of the hydrochloric acid in the marginal cells of the fundic glands, the pepsin being formed in the pyloric end where principal cells only are found. Some have denied this because the alkaline character of the solution found in the pyloric end they say represents an abnormal condition on account of the division of the vagus nerves, hence, it is claimed that the reaction of this part of the gland, like the other, is acid, normally. In the gastric glands the nerve connection is obscure. The stimulation of the vagi and the sympathetics gives no positive results and their division does not retard or arrest the secretion. In cases reported, the sight of food, in the case of starving animals, and in a case reported in which the complete closure of the œsophagus produced a flow of gastric juice, there is an indication that impulses are sent down from the higher centers. In the same case the chewing of food in the mouth, although no swallowing could take place produced a flow of secretion indicating the reflex stimulation in connection with the mucous membrane of the mouth. By making two fistulous openings, one in the upper part of the œsophagus and one in the stomach so that food masticated and passed to the œsophagus, passed out at the opening, the masticatory and insalivation processes produced the flow of gastric juice in the case of the use of animal food. After the division of the two vagi there is no longer any gastric secretion, indicating that by the passage of reflex impulses through the vagi, the first secretion was produced. In confirmation of this it was proved that stimulation of the vagi resulted in the increase of the gastric secretion after a long latent period. From this it is concluded that there are secretory fibers from the vagi to the glands of the stomach, these nerves receiving impulses reflexly from the stimulation of the sensory nerves of the mucous membrane of the mouth.

Heidenhain removed a portion of the fundus making it into a blind pouch,

attaching one end to the abdominal wall in order to form a fistula. The cut parts were stitched together so that the stomach remained continuous, the fundic pouch being entirely cut off from the alimentary canal. When food was digested there was found a secretion in this pouch, the secretion beginning shortly after the food entered the stomach and continuing until it passed through the stomach. By the swallowing of water a similar secretion took place although indigestible matters did not produce any such secretion. The secretion, therefore, depends upon the stimulation of the food and is limited to the parts where the stimulation takes place. Following this initial secretion there is a secondary secretion which takes place when absorption begins in the stomach. This secretion in the isolated pouch was found to belong to the secondary secretion, the stimulation arising in connection with the absorbed products of the food in the stomach, acting either upon the glands of the stomach or upon the intrinsic ganglionic centers in the stomach. These experiments have been repeated by recent physiologists, preserving the nerve connection intact with direct results.

By this means the effect of different kinds of food upon the secretion and its acidity have been studied. During inactivity the gastric mucous membrane is of a pale color not moistened, covered with mucous and in flapping folds. during activity it becomes red and moist, the folds disappearing, and fluid being found at the openings of the glands. If active secretion takes place the blood flow is rapid, the blood being arterial in color so that vascular dilatation accompanies the gastric secretion. As the food is brought into close contact with the mucous membrane, it is probable that the secretion takes place under the influence of local stimulation. This is proved by the application of stimulation to a particular part when the secretion takes place at that point. The secretion was found to begin almost immediately after the taking of food, increasing rapidly until it reaches the maximum about the second hour, after which the flow decreases. With the increase of the flow there is an increase of acidity followed by the decrease in the amount of the secretion. The action of digestion becomes very decided after the second hour. It has been found that the greatest secretion takes place in case of a mixed diet, especially if it consists largely of animal meat. A diet of wholesome bread produces a secretion that is of great digestive power. By the administration of acids, alkalies and neutral acids, no distinct variation in the secretion was noticeable, while the use of water indicated a decided increase in the gastric secretion. The most important stimulation of the gastric secretion occurred in connection with the peptones, producing a large secretion of the gastric juice. It is supposed that the water and peptones directly stimulate the sensory nerve fibers in the mucous membrane, reflexly affecting the secreting glands by the efferent fibers. Thus, the normal secretion takes place on the basis of nerve stimulation. The nerve supply to the stomach is found in the vagi and the splanchnics from the solar plexus. The anterior part of the vagus from the œsophagus is distributed to the smaller curvature, and the anterior part of the stomach, constituting a plexus. The posterior nerve is distributed in the posterior part of the stomach. The majority of the fibers pass to the solar plexus. These vagi branches are almost all non-medullated, only a few being medullated. From the solar plexus the nerve fibers pass with the cœliac artery from branches to the stomach. The fibers from the solar plexus and the stomach are non-medullated. These nerve fibers all lie beneath the peritoneum, passing inward with the arteries to form a plexus between the longitudinal and circular coats, and another plexus in the submucous coat. It is from this last plexus that the fibers pass to the mucous coat. During the

secreting process, the cells, especially the principal cells, manifest great changes. Heidenhain took the glands from dogs that were fed once a day. During the inactivity of the cell he found it large and clear. During the active condition of the cells the principal and marginal cells increase in size, but that in the later digestive period the principal cells become smaller, while the marginal cells continue about the same size, or increase in size. There is a short period toward the close of digestion when the principal cells increase, after which they decrease gradually till they become normal again.

Langley found that the principal cells when inactive were filled with granular matter while during activity the granular matter is used up, first, being removed from the base of the cell, this being the first part to be filled with the non-granular matter. This granular matter represents an intermediate stage in the preparation of the ferments of the gastric secretion, representing therefore, the zymogen, preliminary to the formation of pepsin or the pepsinogen. The glands of Brunner are found at the beginning of the intestine close to the pyloric part similar to the stomach glands at the pyloric end. These intestinal glands have some branching tubules, the cells being identical with the cells of the pyloric glands. The secretion of these glands is small and is supposed to contain pepsin. In the small and large intestines, the Liberkuhn crypts are found similar in appearance to the gastric glands but different in the epithelial lining which is found to contain goblet and columnar cells, the former secreting mucin. It is questionable whether these glands form an independent secretion, the intestinal secretion being associated with these glands, the ferment being invertin. The cells of these crypts are different from the normal secreting cells, so that if their function is secreting they are a peculiar kind of cell. The secretion of the stomach glands, therefore depends upon the stimulation of the mucons membrane either by the food or by some artificial means such as a feather in connection with the mucous membrane, although in the last case, the secretion is very small. In the case of all the cells we have found in the salival pancreatic and gastric glands the same characteristics. The substance of the cells is actively producing part of the cell secretion, the elements assuming the form of granules. This may not represent all the matter stored in the cells. During the cell activity this matter is discharged from the cell in some way, whereas, new matter is formed in connection with the cell substance in order to prepare for still further secretion.

SECTION V. Hepatic Secretion.

The liver is a compound tubular gland. The secretory part of the liver is represented by hepatic cells, the ducts representing the channel along which the bile secretion is excreted from the gland. There are other changes taking place in connection with the liver in the formation of glycogen and urea but as these belong to metabolism and excretion proper they will be discussed later. In the liver, therefore, we have internal and external secretion. The liver is divided into lobules, these lobules consisting of hepatic cells arranged in columns extending outward from the center, the capillaries inside the lobule being so arranged that each one of the cells in these column of cells has blood supplied from the hepatic artery and the portal vein. In connection with the formation of external secretion the bile ducts are closely connected with the minute interlobular branches encircling the lobules. It is difficult to trace out the connection of the capillaries with the ducts of the lobules and the hepatic cells. Each of the hepatic cells has connection with the bile capillaries and also with the blood capillaries, the substance of the cell dividing these capillaries from one another. Recent experiments have proved that the

bile capillaries have direct connection with the cells by means of fine ducts. Much discussion has arisen in regard to the relation of the hepatic cells to the epithelial lining of the bile ducts and the question of the existence of a distinct wall in the bile capillaries. The majority believe that there is no distinct membranous wall in the bile capillaries, these representing simply the spaces between the cells, forming canals along which the bile passes. At the point where the capillaries unite with the ducts the hepatic cells unite with the epithelial lining of the ducts forming a continuous membrane. These hepatic cells are the secretory cells. Several Physiologists have traced nerve fibers to these cells, indicating that the cell activity is controlled by the nervous connection.

Some recent experiments have pointed out the termination of the nerve fibers between the cells without entering into the cell substance. The bile is a composite secretion of a reddish brown color in the human subject. In addition to the pigments, salts, acids and nucleo albumin there is a large proportion of CO_2, loosely combined with the secretion, indicating the great changes that take place in connection with the metabolic processes in the cells. The amount of bile secreted daily can be estimated by means of a canula establishing connection with the bile duct or the gall bladder. It is estimated from 700 to 800 CC daily, or 10 to 14 CC per kilogramme of body weight. The bile must be secreted continuously, the secretion being stored in the gall bladder so as to be thrown out into the duodenum as occasion requires in the digestive process. Its movement from the liver into the alimentary canal is not continuous but intermittent, the excretion taking place in jets like the flow of blood from an artery, this being due to the contractions of the muscular coatings of the large ducts. Thus, while the secretion is continuous the excretion is intermittent.

The secretory activity is closely connected with digestive action. In the case of dogs it has been observed that the secretion becomes much more rapid three or four hours after the beginning of the digestive process, a diminution taking place, followed by another increase toward the ninth or tenth hour. It is supposed that the relation between the digestive action and the secretion of bile depends upon reflex action, some believing that it depends upon the increase in the supply of blood to the liver. If bile is present in the blood it will stimulate the activity of the hepatic cells. From this some have concluded that by the absorption of substances from the bile in the intestine into the blood the secretion is increased. There seems to be a variation in the bile depending upon the nature of the food, the secretion being greatest where animal food is used and less when the diet consists largely of fats. The amount of the bile changes with the blood-flow through the liver. The blood is supplied from the portal vein and the hepatic artery, although the bile secretion continues even after shutting off one of these sources. The material used most abundantly supplied to the hepatic cells is carried to them by the portal vein, the amount and character of the bile depending upon the character and constituents of this blood. If the portal circulation is obstructed the secretion is diminished. By the stimulation of the spinal cord the abdominal viscera become constricted producing a diminution of the portal circulation The secretion is also diminished. If the spinal cord is divided, the bile flow is lessened on account of the paralysis of the vascular system. If the splanchnics are then divided the stimulation of the splanchnics produces a still further lessening of the secretion. If the splanchnics are divided without dividing the spinal cord it increases the bile flow, the dilatation of the abdominal vascular system increasing the portal circulation. These facts would seem to indicate that the bile secretion depends upon the blood pressure, and it is, therefore, a

matter of filtration. Even if the pressure in the bile ducts exceeds the pressure of the portal circulation, the secretion continues. The quantity of the secretion, therefore, will depend upon the quantity of blood flowing through the portal circulation rather than upon the pressure. The actual secretion depending not so much on the amount of blood as on the amount of elements found in the portal circulation, as all these are brought from the alimentary canal in connection with digestion. In the formation of the bile there is no direct evidence of the existence of secretory fibers controlling the secretion because by stimulation the fibers to the liver, vaso motor action is stimulated. The nerve supply to the liver comes from the solar plexus through the hepatic plexus associated with the portal vein, the hepatic artery and the bile duct. The nerve supply to the solar plexus is the abdominal splanchnics and the terminal of the right vagus. From the left vagus there are also small branches. The most of the fibers are non medullated. It has been shown that there are special motor fibers to the ducts and the gall bladder. If the splanchnics are divided and stimulated peripherally, the bile ducts and gall bladder will contract, stimulation of the central end producing dilatation. If the central end of the vagus is stimulated, contraction of the gall bladder takes place inhibiting the opening of the bile duct into the duodenum. This would indicate that the efferent fibers are found in the vagus, the efferent running in the splanchnics through the semilunar plexus. Thus the secretion of bile takes place continuously in the hepatic cells, being ejected into the bile capillaries, the amount depending upon the amount and composition of the blood flowing through the liver, the actual formation taking place in connection with the activity of the cells. While digestion is going on the bile secretion increases. When the bile reaches the ducts it is ejected by the secretion of the new bile, and the contraction of the walls of the ducts. The storage takes place in the gall bladder from which it is ejected intermittently into the duodenum. On account of the vasomotor action in connection with the stomach and intestines there is a full supply of blood in the alimentary canal, this resulting in an increased flow of blood to the portal circulation. Some think there are also rhythmic pulsations in the portal vein resülting in the rapid driving of the blood to the liver and therefore assisting in the secretion.

SECTION VI.--The Kidney Secretion.

The kidney is a compound tubular gland which consists of a secreting part including the capsule, the tubules and the loops and a collecting part consisting of a straight tubular part. In the secreting part, the epithelial lining differs very much in different parts of it. The solid part consists of a cortical and medullary part, the medullary part consisting of conically shaped malpighian bodies, the apex of these bodies opening into the sinus. The cortical portion is of a bright crimson hue. Each Malpighian body consists of two parts, a blood vessel portion, the glomerulus and the capsule, a continuation and expansion of the tubule. The glomerulus consists of a small artery which divide into a number of capillaries, these uniting to form a vein. The entire area represents a peculiar structure so that the blood flow is very slow and the blood pressure high.

Enveloping these glomeruli is the capsule with two walls, the one close to the capillaries composed of flat epithelial cells so that between the blood vessels and the glomerular cavity there are two thin epithelial layers, that of the capillaries and the glomerular epithelium. In this way the filtration from the blood takes place freely. The epithelium of the convoluted tubule has cells of the cubordal or cylindrical type granular in appearance. These cells have im-

portant secreting action. The secretion of urine takes place in the cortical part from which it is carried by the medullary part to the sinus, from whence it passes through the ureter into the bladder. The kidneys are composed of a number of smaller glands closely bound together. The tubules pass almost straight through the medullary part but are very much convoluted in the cortical portion. Every minute tubule starts in the cortical part as a small sac surrounding the Malpighian bodies. This sac is narrow at the neck, and the tubule forming it is very tortuous, passing into the medullary part and forming loops. In the loop there is a descending and an ascending portion, the latter part close to the cortical portion being spiral and forming the intercalary part of the tube, then forming the straight collecting tube. These small collecting tubes unite together, passing to the papillary, forming the papillary ducts. The urine composition is very complex, containing as it does the final excretions of the body in connection with the various body metabolic processes. It is a yellowish secretion with a normal acid reaction due to the presence of the acid sodium and lime phosphate. Its specific gravity is 1016 to 1020. In connection with the secretion it is important to consider the water together with the inorganic substances, the sodium chloride, the sulphates, phosphates and CO_2 and the nitrogeneous products, urea and uric acid. The nerve connection is very complete, the nerve fibers being traced into the basement membrane with terminals between the cells. The blood vessels course freely in the interstitial connective tissues, the veins and arteries running freely through the medullary and cortical substance. The lymphatics are found in connection with the minute arteries and around the capsule, the vessels being accompanied by nerves, the nerve fibers passing through the basement membrane and terminating between the secretory cells.

Two theories are held in regard to the secretion in the kidneys. (1.) That of Ludwig, that the secretion takes place simply by diffusion and filtration, the water being filtered through from the blood in the glomeruli bearing along with it the urea and the inorganic salts. The dilution of this fluid takes place in the passage through the torturous tubes by the process of diffusion in connection with the lymph that freely surrounds these tubules. Recent experiments seem to point to the secretory action of the epithelial cells of the tubules furnishing materials to the secretion. (2.) The latter theory of Bowman and Heidenhain is that water and salts are originated in the glomeruli, while urea arises in connection with the epithelial cells in the tortuous tubes through which the fluid passes in its passage through the kidneys. The secretion thus takes place in connection with the glomerus and also the cells of the uriniferous tubules. It has been supposed that the water is produced by the process of filtration from the blood, although it is questionable if filtration is a correct term to use in speaking of the passage of water and other substances from the blood to the glomerulus into the tubular cavity. The secretion process, however, in the main consists of secretion in connection with the blood flow as in other secretion and also a peculiar secretion, as we will see, due to the peculiar flow through the kidneys. The amount of water secreted depends upon the volume of blood circulated, as well as upon the pressure of the blood.

Heidenhain believes that the epithelial cells of the glomeruli, are active in the process of water secretion. The formation of the water depends upon the physiological condition of these cells, the quantity of urine secreted depending more upon the quantity of blood circulating than upon the pressure of the blood. It seems that recent experiments indicate that the epithelial cells of the tubules take part in the formation of the nitrogenous elements of urea and

kindred substances. If the medulla is divided and urea, urates or sodium acetate are injected into the blood, there is an abundant secretion. It is not accompanied necessarily by a rise in blood pressure. There is a distension of the kidney but the urine secretion is too great to be accounted for by any local increase in blood flow. These substances seem to excite the renal epithelial cells, producing a very abundant secretion in to the tubule cavity. It is accompanied by the vascular dilation but not sufficient to cause the secretion. This indicates the activity of the epithelial cells, indicating a difference between the glomerular secretion and the epithelial cell secretion of the tubules.

If the ureters are ligatured there are urate deposits found very abundantly in the kidneys, these deposits existing in the tubules and not in the Malpighian bodies. The uric acid is thrown out through the epithelial cells of the tubules. Heidenhain by injecting a strong solution of indigo. carmine (sodium sulphindigotate) into the circulation after the division of the spinal cord produced a rapid secretion. The kidneys were then taken out and a precepitate of indigo carmine produced by the injection of alcohol into the vessels. Heidenhain found that the granules were in the tubules and not in the Malpighian bodies. There is no stream through the tubules as the flow of urine is arrested; hence the pigment remains where it is thrown out of the cells. It did not pass through the gromeruli so that it must have been taken up and acted on by the tubular cells.

According to recent investigations definite changes are found to take place in the cells, the secreting matter collecting in the interior of the cells, being afterwards discharged into the cavity of the cells. In birds, for example, urates can be found in the cells of the tubules and none in the capsules. When inactive, the cells are small and granular, the cavity of the tube being wide and the cells towards the cavity exhibit striated processes. When the secretion of fluid takes place it exhibits a bright vesicular area around the neucleus, followed by an enlargement of the cell toward the cavity, as the cavity diminishes in size and the striation disappears. After the cells become enlarged the cavity disappears, the fluid being thrown out by filtration, the cells being ruptured in the ejection of the substances of the vesicules. The water and salt secretion takes place in connection with the glomerular epithelium. The question is, does it take place by simple filtration, or is the epithelium active? If the filtration process was simple the amount of the urine would depend upon the blood pressure in the glomerulus. The kidney is a very vascular organ favoring a rapid flow ot blood. . The renal artery comes away from the abdominal aorta in which the blood pressure is very high. The renal vein passes directly into the vena cava where the blood pressure is very low. Between the beginning of the renal artery and the end of the renal vein, there is a great difference in the pressure, the blood flow depending upon the difference in pressure, a difference equivalent to that found in the entire lower extremities of the body. If the blood pressure rises in the aorta, the blood flow will be greater and, therefore, the pressure would be greater in the blood vessels of the gomerule and vice versa. Experiments have proved that if the arterial pressure is below 40 or 50 mm. the urine secretion is suspended or arrested. If the renal arteries are constricted, there is a diminution of the secretion accompanied by a fall of the blood pressure and a diminution of blood flow. Distension of the renal arteries increases the flow of urine and also the pressure in the glomerular capillaries and the amount of blood flowing through the vessels. It has been concluded that as the pressure of the blood and the amount of urine vary together, the urine secretion depends upon the filtration process of the water from the blood. The variation depends, however, not only upon the pressure

but also upon the quantity of blood flowing through the glomeruli. Heidenhain believes that it is the quantity of blood that determines the amount of urine. The epithelial cells can readily secrete water and do not act simply in the filtration process, the water secretion depending upon the activity of the epithelial cells. If the renal veins are partially compressed the flow of urine becomes slower, or may be arrested entirely. By the compression of the veins the pressure would be raised in the glomerular vessels, and if the pressure theory is correct it would increase the flow of urine. If there is compression of the renal artery the secretion of urine is stopped for a considerable time after the removal of the pressure. This seems to indicate that the epithelial cells are actively engaged in the secretion of water. By the exciscion of the kidneys some experimenters have kept up the kidney activity, proving that the amount of the blood and the rapidity of the blood flow regulated the amount of the urine secretion. This indicates that the greater part of the water is secreted in connection with the living cells of the tubules, although there is also a secretion of water and salts at other parts of the tubule.

How does this epithelial cell activity take place? On the analogy of other glands it would seem that the chemical and physical properties of the cell substance account for this production of water. This activity seems to be promoted, especially by large quantity of blood flowing through the glomerula. The salts that are found in the blood may act as excitants of cell activity, the chief excitant being in all probability, the urea present in the blood and lymph. The urea elimination from the blood does not account for the urea of the urine, because there is less in the blood than in the urine. The urea passes from the blood by some selective process into the tubular cavity. There must be great activity in the cells as the matter is passed into the tubules, as rapidly as it is taken from the blood. The urea seems to act as a stimulant to cell activity. The secretion of the kidneys depends upon the quantity of blood passing through them, therefore, the blood flow is an important factor in secretion. The kidney is an organ ofgreat vascularity when it is active.

It is stated that by the use of diuretics there may be made to circulate through the kidneys a volume of blood equal to the weight of the organs. This would bring into the renal circulation an amount largely in excess of that in any other organ of the body. It is estimated that under these circumstances 5 to 6 per cent of all the blood leaving the left ventricle per minute enters into the kidneys. The blood supply is regulated in the kidneys by the vaso-motor action, this vaso-motor action being effective by acting through the arterial blood pressure. The kidney is furnished with a definite vaso motor mechanism. By the use of Ray's Oncometer an adaption of the Plethys mograph the active influence of the vaso-motor system in the kidneys may be tested. It consists of a box shaped like the kidneys consisting of two parts, connected at the back by hinges and locked together in front. Inside the box membrane is fixed to each part so that olive oil may be placed between the membrane and the metal wall. This forms a soft cushion of oil upon which the kidneys press. The kidney with its nerve and blood connection is placed in one half and then the box is closed so that no exit remains except one for the olive oil which is in connection with the Oncognoph a measuring and recording instrument. As the kidney increases there is an out flow of the oil and every decrease in the kidneys results in a flow of oil, these changes being recorded by means of the recorder. The urine flow can be found out by means of the canula inserted in the ureter. The increased flow of urine is simultaneous with the enlargement of the kidney, that is, with an increased flow of blood, and a diminished urine flow accompanies kidney shrinkage, that is diminished blood

flow. The increase in volume may be produced in connection with the enlargment of the cells, by the accumulation of lymph and the enlargement of the blood vessels, the latter being the most important element. In this way it has been shown that constrictor fibers act upon the blood vessels of the kidneys, these constrictor fibers coming from the constrictor region of the spinal cord in the lower thoracic region. In the dog it is said to be from the 6th dorsal as low down as the 3d or 4th lumbar mainly, however, from the 11th, 12th and 13th dorsal nerves, passing the sympathetics in connection with the splanchnic ganglia through the solar plexus and the renal plexus to the kidneys which they reach as nonmedulated fibers. If these nerves are stimulated there is contraction of the renal arteries, the kidneys decrease in size and the urine secretion is diminished, these being more marked in the case of stimulation of the 11th, 12th and 13th dorsal nerves and less marked in the higher roots. If these fibers are divided dilatation takes place in the arteries, the kidney is enlarged and the amount of blood flowing through it is increased and the urine secretion is also diminished. These nerves are stimulated reflexly and thus exert a continuous influence upon the kidney and its secretions. There are also dilator fibers to the kidneys which produce when stimulated dilatation of the arteries and an increase in the blood flow. These nerves come from the spinal cord by the anterior roots of the 11th, 12th and 13th spinal nerves. The vaso dilator fibers also exist in the higher roots and are accompanied when stimulated by dilatation of the vessels of the other abdominal organs leading to the general fall in the blood pressure counteracting the kidney dilatation. They are stimulated reflexly and thus act upon the secretion of the kidneys through the increased blood supply. In this way there is a direct nervous mechanism controlling the blood supply and therefore controlling the secretion of the urine This is the only direct influence of the nervous system upon the secretion Aside from these local influences and influences affecting the general arterial pressure and flow will have a modifying effect upon the secretion. The kidney is very subject to influences due to chemical action, for example, injecting a small quantity of water into the blood produces kidney distension after a brief period of shrinkage. Urea injected into the blood produces more marked swelling. Similarly sodium chloride solutions and diuretics like sodium acetate. These changes take place even after separation from all nervous connection external to the kidneys. Increase in blood pressure associated with asphyxia or poisoning by strychnine tends to lessen the amount of blood flow through the kidney, and lessens the secretion. If, on the other hand, from any cause the skin vascular system is dilated the blood pressure is lowered and consequently the blood flow is diminished. Any change in the blood that will alter the relation of the blood pressure between the renal vein and artery will increase the blood flow unless this is changed by the contraction of the arteries. Any dilatation of the renal blood vessels on the other hand will increase the flow of blood unless by the fall of blood pressure the force of resistence becomes so strong as to prevent the flow of blood from being sufficiently rapid, and therefore it decreases the amount of blood flowing through the kidneys. With the increase in general blood pressure which implies a rise in the abdominal aorta there is a greater flow through the kidneys, if the renal arteries are not constricted. This may be caused by the heart pulsation and the respiratory movements.

If, however, the renal arteries are constricted as in cases of dyspnœa, the blood vessels are contracted, increasing the blood pressure but the renal vessels are also constricted so that less blood flows through the kidneys. Thus, a general rise in the blood pressure may be accompanied, either by an enlarge-

ment or a diminution of the kidney, and therefore, an increase or decrease in the blood flow. Similarly a fall in the blood pressure will lead to a lessening of the flow of blood in the renal vessels unless it is accompanied by dilatation of the renal vessels as in the case of division of the spinal cord below the medulla. We may conclude, therefore, in connection with these experiments that there are two processes in urine secretion. 1. Glomerular secretion. 2. Secretion in connection with the epithelium of the uriniferous tubules, both of these differing from ordinary secretion such as we find in the case of salivary gland secretion.

(1.) Glomerular secretion. By dilatation of the renal artery there is a more rapid blood flow through the glomeruli, and it exerts a greater pressure upon the walls of the glomeruli. We cannot at present increase the blood flow without increasing the blood pressure, but pressure may be increased without affecting the flow. If the blood is prevented from flowing out through the renal vein the pressure is increased in the glomeruli. This results in the diminution of the flow of urine instead of an increase. This proves that mere pressure does not produce the passage of water through the glomerular loop walls, and therefore, it is not a mere filtration process. All that passes through the loop walls is water and some soluble substances found in the blood, some say proteid while others say there is no proteid at all. In the case of the loop wall we find not only a membrane but also a layer of epithelial cells. The materials found in the urine must pass through these epithelial cells, the cells determining what shall pass through. In order to accomplish this there must be a rapid arterial blood flow assisted by a high pressure. In the epithelium is a condition of derangement as in the case of the cutting off of the blood supply to the glomeruli the uterine secretion will be arrested. On removing the obstruction the urine secretion begins and it will be found to be albuminous so that the albumin which does not usually pass through the epithelium passes through when the epithelium is abnormal. Thus the presence of albumin in the urine indicates an abnormal kidney condition, especially of the glomerular epithelium This indicates the activity of the epithelium of the glomeruli as well as diffusion and filtration in producing the secretion.

(2.) Epithelium of the urinifureous tubules. The epithelial cells of the tubules are active in secretion. If the kidneys are extirpated, or if they are damaged there is an accumulation in the blood of urea. This indicates that urea is not formed by the epithelial cells from kreatin taken from the blood but that the epithelial cells have the power of selecting the urea and extracting it from the blood and then driving it into the cavity. We have no evidence of any process of urea formation in the kidney. If urea is injected into the blood there is no increase in the amount of urea in the urine, but an increase in the urine secretion and flow. In the case of hippuric acid found in the human urine it is formed by the combination of benzoic acid and glycin. If a kidney is removed from the body and the circulation is kept up and then benzoic acid and glycin are added to the blood before it enters the kidney. Hippuric acid will appear in the blood as it leaves the kidney. If the kidney is allowed to die this will not take place so that it is a living process. The cells of the kidneys are supposed to have the power of selecting these substances from the blood and forming hippuric acid. The action of the cells seems to be in accordance with the general kidney function that of secretion in preparation for the discharge of the waste matters from the body, in some cases combining these substances so as to excrete them in a peculiar form. There is a great variation in the substances of urine, especially as between water and solids. It is often advantageous to the system to discharge a large

amount of water. This may take place when the cutaneous discharge is arrested or suspended as in the case of constriction by cold of the cutaneous channels of excretion. The same is true in cases of a large proportion of fluid taken in the form of drink. The amount of water passes to the blood increasing the dilatation of the renal vessels and, therefore, promoting activity of the glomeruli. The substances found in the water may also affect the secreting activity of the glomeruli promoting the secretion. Similar effects are noticed in connection with the emotions increasing the urine secretion. In the case of hysterical urine there is a discharge of urine excessively, the water being in large excess of all the other constituents. In this case the impulses pass down from the brain through the vaso-motors, producing dilatation of the renal blood vessels and thus producing a flow of urine.

SECTION 7. Epidermal gland secretions.

The sebaceous glands are either simple or compound and are found over the superficial surfaces of the body, sometimes associated with hairs and sometimes not, as in the case of the lips and prepuce. In connection with hairs, the short duct connects with the hair follicle so that the secretion passes out in connection with the hair. The cells of these glands are found arranged in layers, those lying nearest the cavity being filled with fat and being destroyed in the formation of the secretion. By the formation of new cells around the basement membrane the secretion becomes continuous. The secretion or sebum is an oily substance containing fat and soap, cholesterin and albumin, inorganic salts and broken down epithelial cells, the secretion varying in character in the different glands in which its formation takes place. The prepuce secretion is called smegma preputii, that of the auditory meatus blended with the sweat glands forms cerumen. On the skin of a new born child there is a sebaceous secretion called vernix caseosa. This sebum physiologically furnishes a protection to the hair and the epidermis. It provides lubrication to the skin and also to the hair, preventing the hair from becoming hard and brittle. In addition it furnishes a protection against the rapid loss of heat from the animal body by evaporation, maintaining normally the epidermal character of the skin.

SWEAT GLANDS.

Sweat is a secretion in connection with the sweat glands of the outer surfaces of the body. These glands are found over all the external surface, particularly in the palms of the hands and the soles of the feet. They are estimated to number between two and three million glands over all the body. In the human subject they are small tubular glands, the end parts of which contain the secretory cells, these cells being knotted upon one another to enlarge the surface of the sweat glands. In the large ducts we find a coating of muscles that plays an important part in the excretion of the sweat from the gland. In the secretory part the cells are columnar in type, consisting of a cytoplasm that is granular. The secretion varies with changes of temperature and also with the mental and physical conditions of the subject. In the average subject the normal secretion varies from 700 to 900 grams daily. It is difficult to determine the composition of the sweat secretion as it is mixed with the secretion of the sebaceous glands. It is a very limpid secretion varying from 1,003 to 1,005 specific gravity with an alkaline reaction. The first secretion of the sweat is normally acid as it is mixed with the sebaceous secretion. It contains in addition to water, sodium chloride, alkaline sulphates and phosphates, urea, uric acid, kreatinin, and albumin with some of the oxy-acids and ethereal sulphates if the sweating is very profuse. If the kidneys are deranged there is

usually a large proportion of urea in the sweat, the crystals being found clearly in the deposits. The sweat nerves are believed to be in the human subject secretory fibers, the secretion being the direct result of the nervous action upon the sweat gland cells. The terminal fibers are brought into close contact with these epithelial cells so that as the result of stimulation of various kinds the production of sweat may take place. An increased external temperature affects the sweat glands through the nervous system, the temperature affecting the sensory cutaneous nerves and reflexly producing stimulation of the fibers of the sweat glands. It is not known where these sweat gland centers are, although the great center is supposed to be located in the medulla. The sweat nerves were first discovered by Goltz, in connection with the cat. The sweat glands in the cat are found in the pads of the feet and it is easy to show the existence of sweat fibers. If the sciatic nerve is strongly stimulated at the peripheral end there may be produced sweat upon the pads of the feet. If stimulation is applied nearer the peripheral end then the same result may be produced. This secretion is characteristically limpid with an alkaline reaction.

Langley has worked out these secretory sweat fibers in the cat. In the case of the hind feet they leave the spinal cord in the 12th thoracic, 1st, 2nd, and 3rd lumbar nerves, join the sympathetics, leaving it as non-medullated fibers in the rami communicantes from the 6th lumbar to the 2nd sacral ganglia and then unite with the sciatic plexus. In the case of the front feet he found the nerves passing from the spinal cord in the 4th to the 10th dorsal nerves, passing thence to the sympathetics and to the stellatum ganglion, from whence they pass as non-medullated fibers to communicate with the brachial plexus. These nerves seem to act directly and not indirectly through the blood. Even after the blood flow has been cut off from the leg, the stimulation of the sciatic still produces the sweat secretion. This is found in the human subject when the palor of the countenance accompanies profuse sweating, the fevered condition of the skin accompanying the absence of sweat. These experiments seem to indicate that the sweat fibers are real secretory nerves directly acting upon the gland cells and producing the sweat secretion. This is confirmed by the histological facts that give evidence of direct nerves to the glands, the fibers ending in the cells. These sweat fibers may be excited in many ways as by heat and muscular exercise. In the case of heat there is a direct action upon the nerve fibers. If the nerves going to the leg be cut and exposure is made to intense heat there is no result produced in regard to the secretion of sweat. The heat seems to act on the sensory heat nerves, producing the stimulation reflexly. The same effect is noticeable in connection with pilocarpin which stimulates the nerve fibers producing secretion, while atropin paralyzes the fibers and prevents secretion. There must be, therefore, some center or centers in the central nervous system through which sweat regulation takes place. It has been taken for granted that there is great sweat center in the medulla which forms the basis of the sweat activity. This seems to be negatived by the fact that when the medulla is divided from the spinal cord the action of certain stimuli still produces the sweat secretion. This has led to the opinion of some that ther are sweat centers in the spinal cord but nothing definite has been formulated upon this subject. Thus we find that the sweat is furnished both by the sebaceous and the sweat glands, the sweat secretion depending upon the character of these two secretions. There is little variation in the sebaceous glands; hence when the sweat is profuse the sebaceous glands have little influence and where it is scarce then the sebaceous glands have considerable effect upon it. Hence, normally the sweat glands may be considered as the sweat secreting glands. There is a slight fluid transudation in connec-

tion with the skin and it is small as compared with the fluid gland secretion because it is greatest where these glands are most abundant. The sebaceous glands do not vary much in their secretion so that the sweat glands are left to do the most of the work. There is a close connection between sweat secretion and the blood supply.

In the horse in which the cervical sympathetic was divided there was found an increased blood supply on the side divided and also increased sweating. In the case of the cutaneous vessels if constricted the secretion is lessened, if dilated the secretion is increased. It is this that aids in regulating animal heat If the atmosphere is hot there is a dilatation of the cutaneous, vessels an increased perspiration and a greater locs of heat by evaporation which helps to cool the body. If the surrounding air is cold the cutaneous vessels are constricted, sweat is scarce and there is much less evaporation resulting in the loss of heat. As we have seen this is controlled by the secretory sweat fibers. The profuse perspiration resulting in the case of the death agony and in the case of mental excitement as well as the anæmic sweats results from direct nervous action.

THE MAMMARY GLANDS.

These glands are like the sweat glands. They are compound glands with acinous structure consisting of small divisions of cells richly stored with albumin and fat. The mammary glands are formed like the sweat glands by a growth inwards of the Malpighian bodies of the epidermis. They consist of ducts that branch off terminating in the secretory cells. The cells differ as they are active during the condition of pregnancy or inactive in other conditions. In the active glands the cell censists of a basement membrane lined by a single layer of epithelial cells. These cells differ at different periods and even at the same period. When the cell is empty of the substance it is cuboidal. the cell consisting chiefly of a cavity. The cell consists of granular cell substance with a nucleus. When filled the gland presents columnar cells jutting out irregularly into the cavity and reducing the size of the cavity. Instead of a single nucleus there are usually two or three nuclei, nearer to the base being one and the others nearer to the margin. At times the marginal part of the cell seems separated from the base and at these times parts of the cell may be found in the cell cavity, within the cell are found oil droplets and granules, some in the substance and others projecting from the cavity. In passing to the empty condition the cells change considerably in size and shape. In the case of the resting gland where the animal has never borne any offspring the cells are much smaller in size being a solid cylindrical mass. They grow very slowly and the metabolic processes send out substances into the blood. When pregnancy occurs the cells grow rapidly, new cells being developed. When the birth of the offspring approaches the fatty cells break off from the colostral fluid, the broken cells being the colostral corpuscles. The cells of which they are composed consist of single epithelial layers. They are said to have originated from primitive skin glands without any mamma, these smaller primitive glands being united together to form larger ones, an opening arising in the skin localized in the nipple. In the human subject they are normally two in number and are localized in the thoracic area. The mammary ducts are not united into a single duct but are grouped together as separate glands representing 15 or 20 separate glands with openings centered in the nipple. These granular cells are imperfectly formed unless during pregnancy when the cells multiply by a kind of cell genesis. during the period of lactation providing for an accumulation of the milk. The fluid secretion consists of a plasma,

and a great number of globules which float in the plasma. These globlets consist of the milk fat, especially the neutral fats, olein, palmitin and stearin together with traces of the fatty acids, lecithin, cholesterin and the milk pigment. The milk plasma consists of water holding in solution proteids, carbohydrates and sàlts. Among the proteid we find casein, lacto-albumin and lacto-globulin in much smaller quantities. The principal carbohydrate is the lactose. A nucleo-proteid is also found the nucleo-glyco-proteid. Traces of urea and kreatin are also found in the plasma together with citrate of calcium, lecithin and cholesterin. This secretion takes place in connection with the epithelial cells as there are matters found in connection with the milk not found in the blood or lymph. During the resting condition the gland manifests in its vesicles a condition in which flattened or cuboidal cells appear with a single nucleus and with a few fat granules. After the lactation commences these cells enlarge the nucleus divides and each cell is found with two nuclei. The fatty matter and the granules pass through a process of change, the cell itself being elongated and these being discharged from the cell end, the discharge and the disintegrated part of the cell being passed into the secretion. Part of this forms the fat globules in the milk and part of it forms the constituent elements of the secretory fluid. Sometimes only a part of the cell becomes disintegrated. Sometimes the entire cell is dissolved. When the entire cell is dissolved the place is supplied by the process of karyokinesis. In the first milk secreted there are found peculiar colostral granules. Heidenhain acconnts for these by certain rounded epithelial cells which in the process of development develop fat cells that are thrown into the gland. Others regard them as due to the dissolution of cells of connective tissue which degenerate and are discharged in the gland during its earliest stages of activity. The milk secretion varies from 1,028 to 1,035 in its specific gravity and if quite fresh is alkaline in its reaction. As soon as it ceases to be fresh it becomes acid. In milk we find various substances.

(1.) PROTEIDS. The chief proteids are casein and lacto-albumin. Under the influence of rennin the casein becomes curdled and insoluble. If milk is mixed with neutral salts or diluted with acetic acid and then a stream of carbonic acid passed through it, precipitation takes place, the lacto-albumin being discovered by means of heating. In the process of curdling casein is divided up into tyrein and an albumose called lacto-protein. The lacto-albumin does not coagulate in the natural milk being hindered by the alkaline character of the milk.

(2.) FATS. In addition to olein, palmitin and stearin we find other fats furnished by the combination of butyric acid and glycerine. There is great variation in the kind of fats present in milk. The milk represents fat in an emulsified condition.

(3.) LACTOSE. This represents the milk sugar which under the influence of a ferment may become lactic acid.

(4.) SALTS. The chief salts are lime phosphates, potassium and sodium chlorides and magnesium phosphates. There are also small traces of iron and sulpho-cyanide. The milk secretion at the commencement of lactation is called colostrum. It differs from normal milk in containing a large number of colostral corpuscles very much like the leucocytes, some of them being regularly formed cells and others disintegrated parts of cells some of which are characterized by amœboid movements. In the colostrum there is also a large proportion of globulin as well as a quantity of albumin. In the disintegration of the alveoli we find the colostral granules. The mammary glands are found in the male and female at birth about the

same condition. After birth the glands become active and discharge a milky fluid after which they remain dormant in the female till puberty when they begin to develop, while in the male they remain dormant except in abnormal conditions. Thus, the mammary secretion while in common with other glands possessing certain characteristics of gland activity have certain peculiar features. In the case of the mammary gland the activity is more definite. As the empty cells become filled, or refilled with secretion the cells grow. The substance of the cells increases in size and by becoming longer it is thrust out into the cell cavity. The nucleus divides and the new nuclei become imbedded in the cell substanre. While the cell substance actually deposits within it the elements of the milk secretion. Following this there is an excretion of the secretion. The fat globules are first ejected from the cell substance and then the cell division takes place, the parts of the cell and the nuclei separating and lying in the cavity of the cells where they pass through certain changes. Thus the elements consist of the cell substance in part and in part of the elements secreted in the cell substance. Thus the nuclein of milk probably arises from the broken up nuclei. In this case the secretion is a manifestation of cell activity. It is from the blood that the elements are extracted but the changes take place in the cell itself. The formation of fat takes plaee in the alveoli, this formation taking place even from proteids when insufficient fat may be present in the food, the cell making this transformation and not simply collecting it from the blood. Similarly the casein is formed in the cell as it cannot be gathered from the blood. Even the albumin is different from the serum-albumin of blood being the lacto-albumin. The lactose, or milk sugar, is also formed in the cell as it is not found anywhere else in the body. Some think that the glycogen like body found in the cells is the preliminary substance in the formation of lactose. The gland is active, therefore, in the secretion of the mammary fluid. It is supposed that mammary secretion is under the control of the nervous system. It has been found that strong psychic influences such as emotions have destroyed or suspended the milk secretion although this is disputed by some. The external spermatic by some of its branches furnishes vaso-motor fibers to the glandular blood vessels, indirectly influencing the milk secretion by the influence exerted upon the blood flow in the gland. The division of the inferior branch has been found to increase the secretion while stimulation results in the diminution of the secretion. It has been found that the stimulation of the sensory fibers in the case of goats lessens the milk secretion. If the mammary glands are severed from all connection with the central nervous system, then the stimulation of any of the afferent fibers has no effect upon the secretion. If the external spermatic is divided on the two sides then the secretion is lessened, whereas, if it is divided on one side only, there is no change in the secretion. In these cases the diminution does not take place at once but comes on gradually. Even after the extrinsic nerves are entirely cut off the secretion continues to take place and the gland becomes enlarged as usual with lessened secretion. The mammary gland, therefore, must be subject to the control of the central nervous system, but whether this takes place through the vaso-motor fibers or through secretory fibers cannot be settled. It seems to be automatic in action, the relation between the mammary glands and the uterus depending upon the blood rather than upon the nervous connection. Recent experiments indicate the close connection of the cells with the secretory fibers but whether this will be confirmed is a matter as yet unsettled. The secretory cells are not formed until after the

first pregnancy the secretion beginning only after parturition, although the cells increase in number during pregnancy. The first secretion is that of colostral fluid differing from the milk in the character of the cells which have wandered about and have passed through a stage of decomposition. After a few days the colostrum gives place to milk which is secreted in the cells and collected in the galactophoric duct, the secretion continuing until the duct is filled when the formation of the secretion is inhibited. As soon as the ducts are emptied a new secretion begins. This process of emptying forms the stimulation necessary to the secretion in the cells. As soon as this stimulation ceases to act the secretion itself ceases.

SECTION VIII. The Ductless Glands.

The internal secretions are formed within the gland, and are passed from the gland, either into the blood or the lymph. In every activetissue in connection with its metabolism there is a waste which is carried into the blood and the lymph. The internal secretions, however, refer to those secretions which take place in definite glandular organs which are used either by the organs or for the metabolism of the entire body. This was first discussed in connection with the testis and pancreas. These secretions are found in connection with what have been called the ductless glands. As yet our knowledge of these glands oud their secretions is very incomplete. In connection with the liver there is a substance formed in connection with the hepatic cells which passes into the blood that falls under this head, namely, urea. It is the principal nitrogenous waste of the proteid metabolism. It passes off from the body through the kidneys, but it is not formed in these glands. It seems to be formed in the liver in connection with certain substances that arise out of the proteid metabolism, these substances being carried to the liver where urea is formed. The urea is secreted in the liver and from thence it is given off to the blood. The hepatic cells perform this metabolism for the entire organism, the liver seems to assist in the utilization of the iron arising in connection with disintegrated corpuscles. There is also formed in connection with the liver cell glycogen in connection with the sugars and proteids brought to the liver by the protal circulation. This stored up substance is eliminated ~~by~~ in connection with general metabolism, in connection with which we will discuss it.

In connection with the pancreas it has been found that there is also an internal secretion. The pancreas has been removed without any immediate fatal results. After the removal of the pancreas it was found that the urine possessed in large excess of saccharine matter. In this case it has been found that this condition of glycosuria follows even when the carbohydrates are taken out of the food. The urine increases in quantity accompanied by a thirsty condition. If these conditions continue the animal becomes weakened and emaciated death ensuing in two or three weeks. Experiments have been made in animals which seem to prove that the partial removal of the pancreas prevents the accumulation of sugar in the urine; 1-4 or 1-5 of the pancreas being sufficient to prevent this accumulation of sugar in the urine. From this it is concluded that there is a secretion in the pancreas which either consumes the sugar, that is produced in the organs of the body, or else prevents the sugar from being eliminated from the liver and the body tissues. It is claimed that recent experiments prove that in cases of diabetes there is post mortem proof of this disease being connected with certain variations in the pancreas.

The thyroid bodies are glands found in the human subject joined together in front of the trachea by a narrow band. It is a double lobed sacculum, the two lobes being united together without any duct. These consist of masses of

alveoli connected together in connective tissues which send septa into the interior, separating the alveoli from one another by oval spaces. In connection with these septa we find numerous blood vessels springing from the superior and inferior thyroid arteries whose branches surround the alveoli in networks of capillaries. From these the veins collect the blood, forming plexuses in the organ surface ending in the inferior and middle thyroid veins. Around these septa we find also a large number of lymphatic vessels arranged in plexuses, the nervous connection springs chiefly from the cervical sympathetics, from the middle and lower cervical ganglia. They consist of a large number of closed cells of varying sizes. each cell being covered with epithelium and filled with a slimy fluid, this fluid is a gluish liquid called colloid, the secretion of the cells of the thyroid, first secreted in the cells then thrown out into the cavity of the body. It is believed by some that this fluid is finally discharged into the lymphatic system. This colloid is a somewhat gliary and solid substance, this glairy fluid consisting of mucin, although some think it is not pure mucin. In addition to this the alveoli contain serum albumin and globulin. The thyroid extractives are found to contain kreatin, xanthin and lactic acid. From the presence of the mucin it has been suggested that the thyroids have something to do with the formation and distribution of mucin. In some animals there are found accessory thyroids found in different parts of the upper portion of the body which in case of the removal of the the thyroids, discharge the functions of the thyroid bodies. If the thyroids are much enlarged we find a goitre condition and also the cretinous condition which is associated with a form of idiocy. The extirpation of the thyroids in animals is attended with fatal results, death being preceeded by muscular twitchings which sometimes pass into spasms and also by a condition of malnutrition almost amounting to emaciation, These muscular conditions depend upon the nervous system as the division of the motor nerves frees the muscles from such action.

It is supposed that this nervous action arises from the changes in the brain and spinal cord. In the lower animals fatal results have not always followed thyroidectomy, perhaps chiefly because of the existence of accessory thyroids, which on the removal of the thyroid, take their place. Where the thyroids are removed the red corpuscles are diminished in numder and the white increase very much, salivary glands are enlarged, the parotid gland secreting mucin and blood. Where fatal results follow, they are more rapid in the case of young than in older animals. In the human subject the fatal results are much slower in appearing, being accompanied by anemic conditions, muscular debility, loss of mental capacity, and characteristic subcutaneous swelling. If a small part of the thyroids is left then the fatal results do not follow, in the lower animals it is claimed that fatal results may be obviated by the grafting of a part of the gland in some position under the skin or in some other portion of the body easy of access to the blood. According to Horsley there are three stages following the removal of the thyroids. (1) The neurotic period during which muscle twitchings and nervous excitement are accompanied by a dyspnoeic condition. (2) The mucin period during which myxœdema is developed, mucin being deposited in the tissues, and, (3) the atrophic stage during which the muscles become atrophied. The thyroids, therefore, have an important function in connection with the body metabolism. According to some their function is to absorb and take out of the blood certain noxious substances which would interfere with the metabolic processes. The removal of these bodies produces a condition, it is said, of auto-toxication, these toxic substances accumulating in the blood. In proof of this it is claimed that the blood and urine of animals from which the thyroids are removed has

a peculiar toxic influence, if injected into other animals. These results are denied by some physiologists. If the thyroids become enlarged we find the exophthalmic goitre with protruding eyeballs. 2. According to others, the thyroids secrete a fluid which is a true internal secretion and when discharged exercises a potent influence upon metabolism, especially the metabolism of the nervous system. In proof of this it is claimed that to inject thyroidal extracts produces good results. This substance formed in the gland reaches the blood through the lymbhatic system after it has been secreted within the cells of the gland. This last fact proves that there is a true internal secretion, and if this is so, then it must have an important bearing of some kind upon metabolism. Some have been successful in extracting from the gland a substance called thyroidin which is found to contain a large quantity of iodine, often as much as ten per cent of the dry substance and which is found to have good results in cases of goitre and myxœdema. This proves that the thyroid produces an iodine compound and it has been found that this compound consists of a combination with proteids. Recent experiments have indicated the presence of a number of such compounds all of which are found to be valuable in the body metabolism. The larger part seems combined with thyroid-albumin, the smaller part being combined with a thyroid-globulin. These substances when given to animals upon whom thyroid-ectomy has been performed have good results.

The suprarenal capsules or adrenal bodies form another of these ductless glands. Surrounding the bodies are the connective tissue capsules, septa passing inward from the capsule forming a frame-work of cells of different structure. The substance of the cells is of a yellowish color, sometimes containing yellow oil globlets with a distinctly marked round nucleus. In the cortical part the cells are of different kinds, some columnar. In the medullary part the cells are different, the substances of the cells being clear and transparent and distinguished from the cortical part by the abundance of blood vessels and nerves. The nerves are chiefly medulated nerve fibers from the solar and renal plexuses, the phrenics and vagi nerves entering suprarenal body and forming plexuses' the fibers ending in the cortical and the medullary parts. The substances found in the suprarenals consist of proteids and also some substances containing peculiar color reactions. The histological character of the cells suggests that certain processes take place in the cells in connection with the pigment metabolism of the body. As the nerve connection is very complete there seems to be a close connection with the nervous system. The complete extirpation of these bodies is followed by death, the fatal effect resulting more quickly than in the case of the removal of the thyroids. Following the removal we find muscular and mental exhaustion and a marked blood depression. These results correspond with the conditions in connection with Addison's disease, in which case there is a suprarenal disturbance. Addison first noticed that diseased conditions of the suprarenals involved a bronzing of the skin, accompanied by giddiness, vomiting and dyspnea. In cases of Addison's disease it has been found that adrenal extracts have a good effect. It has been claimed that death results from the removal of the suprarenals on account of the presence in the body of a toxic substance it produces auto-toxication. Others have claimed that the suprarenals discharge an important function in connection with the muscles secreting a secretion that has a very definite action upon the muscular system. Solutions of the medullary part of the gland have been found to exert an influence upon the muscles of the heart, the blood vessels and the skeletal muscles. In the case of the heart it was found that on the division of the pneumogastrics the heart's action became stronger, whereas,

muscular contraction became more protracted, the blood pressure being greatly increased. From this it is concluded that the secretion of the suprarenals is constantly of value to the muscles and other tissues of the body acting as a stimulant.

In regard to the pituitary body it is claimed that fatal results follow its complete extirpation and that it follows the same course as death from thyroid ectomy indicating that they perform the same function or similar functions in the body metabolism.

In connection with the reproductive glands Brown-Sequard has made a number of experiments. Fresh testine injected into the blood has a remarkable tonic influence on the nervous system, especially in connection with the spinal centers, in cases of neurasthenia and general debility. This is said to be due to the presence of a substance in the secretion which passes into the blood. A substance called spermin extracted from the secretion by Brown-Sequard has been found to materially assist the metabolic processes, not only having a tonic influence, but also diminishing body and mental fatigue and increasing the efficiency of the neuro-muscular mechanism of the body, preventing muscular and nervous exhaustion and also diminishing the sensations associated with exhaustion.

The spleen is an organ whose functions as yet are not distinctly understood. The spleen may be removed without any fatal results, the noticable effects being that after its removal there is an enlargement of the lymphatic glands and an increase in the bone marrow together with an increase in the activity of the medulla. It has been found that one result of the removal of the spleen is the decrease in the number of the red corpuscles and the amount of the haemoglobin. From this it has been infered that the spleen has something to do in the formation of the red corpuscles. The chief known facts about the spleen are in regard to its movements the spleen is known to increase in size during digestion attaining its maximum about five hours after a meal, remaining for a time enlarged and afterwards returning to its normal position. This is possibly due to the action of vaso-dilator fibers and the relaxation of muscular contractions in connection with the capsule and trabeculae; the relaxation of tonic contractions being the most important factor. By the use of the plethysmograph, a spleen curve can be made. The variations in the volume corresponding with the respiratory movements. This enlargement is noticable in pyrexia accompanying fevers, especially ague, in some cases the enlargement becoming permanent.

The spleen also manifests slow rhythmic contractions and expansions and alterations in size, corresponding with the variations of blood pressure and coincident with the respiratory movements. These alterations are determined by the contractions and relaxations of the muscular fibers of the spleen, and also the change in calibre of the arteries, both of these changes being regulated by the nervous system. The expansion of the spleen does not take place according to the blood pressure for there is a resistance on the part of the muscles which retards expansion. The spleen is a muscular organ expanding to receive a large volume of blood and contracting to send it on to the liver. In the spleen there is a special local circulation, the spleen being abundantly supplied with nerves, which upon stimulation cause the decrease of the size of the spleen. These nerve fibers are found in the splanchnics containing both inhibitory and acceleratory fibers. The splenic circulation is carried on largely by means of these contractions. These contractions being quite regular in their movements. If the central end of some of the sensory nerves is stimulated the spleen contracts; similarly if the peripheral ends of both vagi and

both splanchnics are stimulated it produces a quick contraction of the spleen. If both the vagi and splarchnics are divided and a sensory nerve is stimulated contraction of the spleen takes place. What the object of these rhythmic movements is as yet unknown but they seem to depend upon the small ganglia which acts as automatic centers. These contractions and relaxations vary considerably, depending upon the blood supply determined by the needs of the organ and upon the needs of the liver which are largely guided by the blood changes in the spleen. In the spleen there is found a large proportion of iron together with fats, fatty acids, cholesterin, nitrogenous extractives, xanthin, uric acid, etc. The uric acid is always present. The existence of these substances seems to indicate that certain active changes take place in the spleen in connection with the metabolic processes of the body. During foetal life it is certainly a producer of red blood corpuscles Uric acid is said to be produced in the spleen. Uric acid is always present in the spleen but whether it is formed in the spleen is not as yet settled. If so, then it must be formed in the spleen as well as in the lymphoid tissue generally, but nothing definate can be stated as the removal of the spleen may take place without any serious interferance with the economy.

SECTION IX.---2. Excretion.

We have seen how the food passess through the digestive process and by absorption, passes through the blood to the different tissues of the body. In passing through the blood and tissues, certain changes take place, the excess of fluid being carried as waste into the lymphatic system and through the lymph into the blood. The varions food elements, proteids, fats, carbohydrates, salts and water become changed, the proteids, fats and carbohydrates into urea, CO_2, aqueous vapor, (H_2O), the proteids producing nitrogen. From the proteids also are found sulphur and phosphorous which becomes changed by oxidation into the sulphates and phosphates being excreted along with the salts. These waste substances that find their way into the blood are not only excess but they represent dangerous elements if continuously accumolated in the blood. These substances that are eliminated are called excretions. Generally speaking, these waste elements consists of urea, CO_2, salts and water. These waste matters are eliminated through five different channels, the lungs, the intestines, the liver, the skin, and kidneys. As we saw in connection with respiration the lungs excrete CO_2 and also a quantity of aqueous vapor. In connection with the intestines we find then in the form of faeces, the undigested parts of food and the matter secreted in the intestines are excreted as faecal matters There remain to be considered, the two main excretory organs, the skin and the kidneys.

(1.)—THE SKIN.

It is concerned physiologically with the functions of sensation, protection, respiration and also excretion. It presents a sensory surface between the internal substances and the organs of the body and the external world. It has a variety of nerve fibers distributed over its surface that give rise to various reflex actions that keep the body in adaptation to its surroundings It also has an important part to play in connection with animal heat and body temperature. The skin sonsists of two layers, the deep layer of connective tissue called the corium or dermis, and the superficial layer of epithelium called the epidermis. In connection with the skin we find two kinds of glands, the nails and hair, developed in connection with the epidermis. The corium consists in its upper surfaces of furrowed and cross furrowed areas forming either rounded

or grooved shaped areas, the rounded areas appearing on the surface of the skin and the furrows on the palms of the hands. Between the furrows are found the papillae varying in size and number in different parts of the body, being largest in the palms of the hands and the soles of the feet and also most numerous. This corium consists of connective tissue interlaced with elastic fibers. The mesh work of tissues differing in the different layers, two of which are important, the papillary and the reticular, the latter or deeper layer presenting numbers of fat cells underneath these being the subcutaneous layer in which fat cells are abundant. The subcutaneous layer of tissue passes into the muscle fascia or bone periosteum. The epidermis consists of tesselated epithelium with at least two strata, the deep or soft stratum called the Malpighian or mucous stratum and the dense or corny stratum. Both strata consists of epithelial cells. In the mucous stratum being cylindrical with a long nucleus, those above being round or flattened cells. In the corny stratum are found polyginal cells flattened without any nucleus, these being formed from the hitherto developed mucous layer cells. The pigment of the skin is found in the deeper cells of the muscous stratum. In thick epidermal regions as in the hand and feet, there is a middle layer lyi ng between the deep and the dense layer called stratum lucidum, Connected with the skin, are hair consisting of the shaft, that part above the skin, the radipili the part passing into the skin, sunk in the folicle and the bulb at the end of the root with a tubular recess filled with tissue called the papillae. The sebaceous glands open into the folicule.

SECTION X.---Sweat and Sebaceous Excretion.

In connection with the integument we find two glands. (a) The sudoriferous or sweat gland. These were first discovered by Malpighi. These are tubular glands, ball shaped, at the end, being the secreting part and situated in the subcutaneous tissue. The long straight duct passes with a slight winding course through the corium between the papillae running through the horny epidermis and opening on the surface by a round pore. These glands are found all over the body except on the glans penis and on the inner surface of the preputium penis being found most abundant in the palms of the hands and the soles of the feet. There are estimated to be as many as 2,500 to the square inch. Krause estimates that there are two million, five hundred thousand sweat glands over the body The secretion of these glands is an oily fluid which lubricates the skin. normally during the resting condition. Under the influence of nervous stimulation, the watery liquid known as perspiration, is exuded.

(b). The sebaceous glands are simple or compound racemose glands. They are found in the corium and consist of a short duct opening into or in connection with tubes that open into the hair follicles. The secretion is a fatty matter mingled with the remnants of broken up cells These glands are found all over the body except on the palms of the hands and the soles of the feet, some of these glands not being connected with hair follicles as on the lips, the labiaminora, the glans penis and the preputium penis known as Tyson's glands. In the negro races, these glands are found very large and numerous, sometimes being developed deep into the subcutaneous tissue. The subcutaneous arteries arise from vessels in the underlying fascia running out to the surface. They consist of three capillaries, the deeper lying in the fatty subcutaneous tissue, the middle forming a plexuses around the sweat glands and the most superficial forming the terminals of the artery, furnishing branches to the papilla, the hair follicles and the sebaceous glands in the papillary stratum.

In the papillary stratum arise the veins in connection with the papilla, the hair follicles and the sebaceous glands, the small vein branches etering close to the arteries and receiving branches from the sweat glands and passing into the fatty subcutaneous tissue. The lymphatics consist of two net works, the one lying in the deeper subcutaneous tissue with wide meshes and the other in the papillary stratum with very narrow meshes, the branching lymphatics arising around the hair follicles and the glands. The nerves are very abundant in the palms of the hands and the soles of the feet, having their terminals in the subcutaneous tissue and also in the touch corpuscle cells. The horny layer of the epidermis acts as a surface of protection and also as a barrier against absorption of poisonous substances. Each of the epidermal structures represents a development in connection with the excretions from the blood, each of these structures having its own constitution and independent existance, growing and maturing and then being replaced by others, which grow in the same way. These epiderminal structures are connected with the protection of the body aiding sensitiveness, warmth, etc. A limited quantity of water may be absorbed through the skin. Other substances particularly if mixed with fatty or oily substances especially in connection with mechanical rubbing, pass through the skin into the subcutaneous lymphatics. The epidermis is a medium through which the nerves of ordinaary sensation receive stimulation, and it may be that the deep cells of the stratum mucosin are to be regarded as the terminal organs of these nerves, the actual termination of the nerve fibers in the cells have not yet been enough definately made out. To a slight extent, respiration takes place through the skin, about 10 grams of O being absorbed and about the same amount of CO_2 being given off in the course of 24 hours, but the chief function of the skin is that with its glands, it presents a large surface through which excretion takes place. The chief substance excreted through the skin is water, with a comparatively small quantity of salts and a small quantity of CO_2. In the human subject the perspiration takes place largely on the forehead, on the palms of the hands and the soles of the feet, and the axillæ.

(a) SWEAT. The sweat yielded by the sudoriferous glands is a colorless, watery fluid transparent with the peculiarly saline taste and a characteristic odor varying in the different parts of the body. The sweat in the human subject is acid in reaction, although it is alkaline when very abundant. If a part of the skin is well washed, the sweat collected afterwards from the skin is alkaline. It is concluded from this that the pure sweat is alkaline, but that when mixed with sebum secretion it becomes acid. This acidity is due to the sebaic acids arising from decomposition of the sebaceous matter found in connection with the sweat glands. The specific gravity is about 1.004 On microscopic examination there are found oil globlets and crystals and sometimes some epithelial epidermic cells. Normally perspiration contains 97.5 to 99 per cent of water, and from 1 to 2.5 per cent solids. About two thirds of the solid matter consists of organic matters and one-third of inorganic substances in the form of salts, sodium chloride constituting the larger proportion, from 0.2 to 0.3 per cent, and small quantities of other inorganic salts, there are also found phosphates and traces of iron oxide, some traces of urea have been found representing proteid decomposition, but this normally is decomposed, giving rise to ammonium salts. It has been proved that where muscular activity is great the amount of nitrogenous waste eliminated from the skin may be considerable, amounting to .8 grams. Under ordinary circumstances, however, the amount of urea eliminated is small. Small quantities of the volatile fatty acids are present, giving rise to the sweat odor. Lactic acid is not present in a normal condition.

There are also found the neutral fats, cholesterine and small traces of albumin, various fatty acids such as buteric and acetic acid with caproic and caprylic acid giving rise to the odor. In pathological conditions sweat has been found to contain blood, urea and albumin in large quantities, sugar, uric acid, lactic acid and bile also in large quantities. The amount of sweat varies in different animals. Anything that assists the blood to supply the skin, tends to assist sweat secretion, and if the watery evaporation is greater from the glands than normal the surface of the skin is covered over with a profuse perspiration. Secretion of sweat is produced by exercise, profuse drinking of water, hot baths, high temperature, and friction applied to the surface of the skin. Morphine and atropin diminish or stop the flow of sweat, whereas muscarin strychnine, nicotine and camphor increases the sweat flow. Mental conditions of excitement, either of excessive joy, anger or grief increases the secretion of sweat. There is a sympathy between the two excretory organs so that if the action of the kidneys is partially arrested as in certain abnormal conditions, the skin will discharge the excretory function more generally. It is estimated that about 900 C.C. of water is discharged by the skin in 24 hours in a normal adult or about 100th part of the body weight. This represents the second channel through which water is excreted from the body. It is very much less in proportion than that excreted by the kidneys. It seems to be important not so much from the standpoint of water excretion from the body as in connection with the loss of animal heat, or its preservation. The more sweat is evaporated, the greater is the heat loss. The first sweat secreted is more rich in fatty acids and salts with less inorganic salts, the reverse being true when perspiration becomes free, then the secretion becomes alkaline. Free perspiration lessens the flow of urine and at least diminishes the quantity of urea found in the urine. Iodine, alcohol and odoriferous elements may be discharged through the skin. The sweat secretion is dependent upon the blood pressure in the minute capillaries, the development of the gland cells and the nerve supply to these cells. After the secretion takes place the excretion is aided by the contraction of the smooth muscular fibers found between the cells and the membrana propria. Perspiration is more profuse on the right side than on the left side. The innervation of the sweat glands depends upon the vaso-motor nerves. the dilators and constrictors, and the trophic or secretory fibers. Perspiration will not be produced by the simple effusion of blood to the surface of the skin. Pallor may be found along with profuse perspiration, in this case the vaso-constrictors and the secretory fibers are active. There is no doubt that special secretory fibers are in existence. If the sciatic nerve in the cat is cut and stimulation is applied to the peripheral end perspiration will be found freely in connection with the foot pads. In the case of the cat perspiration in the hind feet depends upon nervous impulses conveyed along the sciatic nerve fibers. A cat whose sciatic nerve was divided on one side when placed in a hot room was found to perspire freely in the three feet while the foot in which the sciatic nerve was divided did not sweat at all. These secretory fibers in the sciatic nerves originate from the spinal cord from the anterior roots in the spinal nerves, from the ninth to the thirteenth dorsal vertebra. Some have located in this spinal area a spinal sweat center. The secretory nerves of the front limbs in the cat are found in the median and ulnar nerves arising from the spinal cord in the lower cervical region. The secretory fibers of the head and neck have been found in the cervical sympathetic, in the facial nerve and the fifth cranial arising from a brain center, possibly one of the cerebral centers as the mental states of excitement, emotion and pain produce influences affecting the sweat glands of the face and neck.

The stimulation of the facial nerve has been found to produce perspiration on the cutaneous region supplied by this nerve and also on the opposite side. The same is true of the median nerve. This seems to indicate reflex action in connection with the sweat centers. In what way this takes place is as yet unknown. If the perspiration is not very profuse and if the atmosphere around is dry, the watery fluid in the sweat passes off quickly as vapor, this vaporous element being called insensible perspirations. If, on the other hand, perspiration is profuse or if the atmosphere is moist the sweat freely flows over the surface of the skin and it is called sensible perspiration. The proportion of these two will depend on the secretion in connection with temperature and the motion of the surrounding air. When the air is dry and hot and the air in contact with the body is rapidly renewed, the sensible perspiration is greater and a greater amount becomes insensibly evaporated. It the air is cool and moist there is a large amount left on the skin as sensible perspiration. Often we seem to perspire freely, when really there is but an increase in the sensible perspiration. The secretion may increase in a hot, dry air. The condition of the body also determines the amount of perspiration given off, for example, the quantity and kind of the food, the amount of fluid taken, the exercises of the body and the activity of the kidneys. If the skin surface becomes covered with solid substances, the skin will be coated so as to prevent the free action of the sweat, the openings into the ducts being closed. This constitutes one of the fundamental reasons why baths should be regularly taken by persons desiring to maintain normal health so as to keep the pores of the body open and to permit the free and active exercise of the sweat glands.

(b.) THE EXCRETION OF THE SEBACEOUS GLANDS. The substance secreted is of an oily character, semi fluid and of a characteristic odor. The fatty substances are formed by the epithelial cells of the glands, the sebaceous secretion consists of about 31 per cent of water, 61 percent of albuminous matter and broken down cell substances, 5 per cent of fatty matter and soaps including olein, palmatin and sodium palmitate with 1 to 1.5 per cent inorganic salts including the chlorides and phosphates. Its chief function seems to be in connection with the hair keeping the hair soft and flexible. It has also a function in connection with the skin, lubricating the skin and preventing the loss of water and also hindering the absorption, of aqueous substances through the skin. This includes the wax formed in connection with the ears and the secretion of the eyelids. The earwax is said to contain fat cells and cholesterine crystals together with a bitter substance not yet named. The amount of oily matter secreted varies among animals according to the species and even among individuals being largest among the negroes.

(c.) GASEOUS EXCRETION. The skin from the standpoin of respiration is concerned in the exchange of gases. The capillary vessels in the outer layer of the corium contain O and CO_2 and as the epidermis is the only separation between the gases and the atmosphere the exchange takes place upon the bases of the lose of diffusion the CO_2 being given off and the O being taken in to unite with the hæmoglobin. Aqueous vapor, H_2O, is also excreted through the skin when the surrounding air is not freely filled with such vapor. In the case of a frog whose lungs have been taken out respiration continues for some time, O being taken in and CO_2 eliminated. the frog being able to breathe without lungs, the respiration being carried on by the skin. In the human subject this respiration is limited on account of the thickness of the skin. By the enclosure of the human body in a gas tight chamber it has been found that by shutting out the respiratory gases the quantity of CO_2 given off in a day amounts to from 6 to 10 grams, similiarly from 6 to 10 grams of O

have been absorbed by the skin in a day in the case of the human subject. This large amount of CO_2 does not necessarily come from the blood but may arise in connection with sweat decomposition and the O may be similiarly absorbed and used up in the oxidation process in connection with the sweat. It is estimated that CO_2 is given off by the skin to the extent of 1-150 and O taken in to the extent of 1 140 of that given off and taken in in connection with the lungs. The amount of aqueous vapor excreted cannot be estimated as it cannot be collected free from the sweat. This indicates that the exchadge by the secretory process of the skin is small as compared with the amount of gas required in respiration. If a rabbit is covered over with gelatin so as to prevent absorption of O or water and an exhalation of CO_2 and water, the rabbit will soon die. This death is not due to the suspension of cutaneous respiration as it is small compared with that of the lungs. These symptons seems to indicate poisoning accomopanied by a large loss of heat indicated by the fall of temperature If the warmth be preserved by the use of cotton so as to prevent the heat from being rapidly lost life may be prolonged. The skin also absorbs.

Cases have been recorded in which by emersion in water the body has increased in weight, this gain being due to the embibing of water by the skin. If the epidermis is removed absorption takes place rapidly but some have questioned whether such absorption is possible if the skin remains intact. It seems that there can be no reason why water and soluble substances should not pass through the intact skin. There is evidence that even solid substances may pass through the skin as solid particles rubbed into the skin if in a fatty medium become quickly absorbed in the lymphatics.

The formation of sweat is influenced by the same circumstances that influence the formation of other excretions, namely: (1) the supply of blood; (2) the nervous impulses; (3) the activity of the grandular epithelium. Hence, where cutaneous vessels are dilated, as, when the surrounded atmosphere is warm the excretion of the skin is increased while under opposite conditions the perspiration is very scanty in amount. The effect of nervous influences independently of the blood supply to the sweat glands upon the formation of sweat has, as in the case of submaxillary gland been demonstrated by experiments upon the lower animals. The phenomena of increased sweat under excitement, emotion, etc., is a well known example of these influences in connection with the higher centers. Simularly the cold sweats of phthisis in which pathaological condition there is not an excessive but a defective blood supply to the cutaneous vessels, form examples of the influence of body conditions upon body perspirations.

SECTION XI. (2) The Kidneys.

The kidney consists of a cortical and medullary part, the medullary part being formed into the pyramids of Malpighi conical shaped masses whose apices open into the sinus. The cortical portion is soft and of a dark color. The secretion takes place largely in the cortical part after which it passes through the medullary part into the sinus from which it passes into the pelvic cavity of the ureter and thence into the bladder. In the kidney we find a large number of tubular glands closely connected. The tubes (tubuli uriniferi) being very tortuous in the cortical portion and straight in the medullary portion. Each of the tubules originate in a small sac constricted at the neck encompassing Malpighian bodies in the cortex, the tube in convoluted form running into the medullary part forming a loop and returning to the vortex constituting the Henle loop, consisting of a descending and ascending portion. The ascending

portion becomes spiral and forms the inter-calary tube and then straightens out into the collecting tube. These collecting tubes as they pass to the medullary part unite together forming larger tubes which become papillary ducts in the papillæ. These minute tubules vary in size at different points of the path, the smaller tubules passing into the inter-callary ducts and finally into the wide collecting tubes. These tubes lie in the midst of loose masses of interstitial connecting tissue in the midst of which the minute blood vessels are found. The Malpighian corpuscle forms a plexus of blood vessels, known as the glomerulus encompassed by the expanded section of the urinifierous tubule called Bowman's capsule. This capsule consists of two portions, the internal covering the glomerulus and the external consisting of polygonal cells passing to the neck and forming the convuluted tube wall. The renal artery branches into the renal substance passing through the medullary part and passing up to thebounding line between the medulla and the cortex forming a series of plexuses with the convex parts towards the cortex. Out of these convex arches arise the interlobular arteries which branch off into the lobules each glomerulus receiving one branch which is divided so as to form afferent vessels with capillaries branching off into the interlobular efferent veins. These minute veins anastomose freely with the veins in the cortex, running quite close to the interlobular arteries. The arteriæ rectæarising from the arterial arches supply the medullary portion of the kidney, the medullary veins running in spiral form around the papillary ducts and opening into the venous arch at the bounding line between the medulla and the cortex. The renal lymphatics are found in connection with the capsules and the minute arteries in the renal substance, nerves accompanying the minute vessels, but with connections and terminations as yet unknown.

SECTION XII. Urine Composition.

The kidneys are functionally the organs through which the urine is secreted and drained off from the blood. Through them the main part of the nitrogenous waste of the body with a considerable quantity of water, some salts and CO_2 are excreted. The sold matters of the excretions of the body are excreted chiefly through the urine, only a small quantity passing through the skin and almost none through the lungs. Thus, all the substances are practically excreted through the urine except the fæces, these substances vary considerably in quantity and in composition.

The normal urine is a clear yellowish, slightly phosphorescent fluid with a peculiar odor and a saline taste. It is acid in reaction, the acidity being due, not to a free acid but to the presence of an acid salt, phosphate of sodium, the degree of acidity depends upon the diet, being said to be in inverse proportion to the acid secretion in the stomach. Thus, it varies with the kind of food. After taking a meal, the urine may be neutral or alkaline increasing after digestion in the stomach ends. In carnivorous animals it is acid and in herbivorous, alkaline, if living on vegetables but if starving or living on animal diet then it is acid. When the food is animal there is more acid production than can be neutralized. When the food is vegetable there is carbonate formation sufficiently great to neutralize the acids. With a vegetable diet the proportion of alkaline salts excreted in the urine is increased and that fluid becomes less acid, neutral, or even alkaline in reaction When the gastric juice is being secreted as when food is taken into the stomach the acidity of the urine is decreased. As digestion becomes more complete the urine becomes again distinctly acid. On exposure to the air for a time urine becomes more markedly acid, as fresh acid is formed by fermentation and urates or uric acid

may be deposited, but subsequently the reaction changes to alkaline, the urea combining with elements of water to form carbonates of ammonia under the influence of micro organisms or organized ferments. These do not normally appear till the urine is discharged. Sometimes abnormally, however, fermentation takes place in the bladder, micro organisms being introduced from the air or an unorganized ferment bein formed inside. A deposit is also thrown down, the phosphates being precipitated partly as phosphates of lime, partly as the triple phosphates of magnesium, and urate of ammonia. The urine temperature is normally about 39° C after standing for some time there is a mucous deposit representing mucous corpuscles and sometimes flattened epithelial cells. Later this deposit will yield uric acid crystals, and still later the acid urate of sodium. If kept in a clean vessel and in the cool the acidity continues for some time. Later the acidity lessens slowly and then it becomes neutral and later alkaline, fermentation setting in on account of the presence in it from the air of the micrococ-cus ureæ. Microscopic examination revealing the presence of bacteria. If urine is preserved in a clean vessel and then boiled and caresully sealed it will keep for a considerable time. Under the action of the micro oaganisms urea is converted into carbonate of ammonia, a deposit being thrown down consisting of the triple phosphate, lime phosphate and ammonia urate. Urine may be alkaline if the alkalies are present if acetates, citrates, phosphates are found in the food.

The mean specific gravity is 1020, varying from 1015 to 1025. The color of the urine varies both in health, and disease. It may be pale, colorless or dark color. In diabetes it is usually very pale. It may be milk colored on account of the presence of chyle; dark red from the presence of a pigment or blood or greenish from the presence of bile. It may also be a bluish color due to the presence of indigo from indican. The normal variation in color depends upon the varying quantities of the pigment, urobilin which is the same as bilirubin taken from the alimentary canal. In order to find out the urine composition the urine must be collecte for a day and then subjected to analysis. This must be done in order to have a normal urine as it is subject to great change during a day. The amount of urine secreted by a normal male is about 1,800 to 2,000 CC, and an adult female from 1,400 to 1,600 CC. Sometimes it is necessary to estimate the amount of certain elements found in the urine by the volumetric method. Certain reactions are used, the solutions used being of definitely known strength, the weight of the substance being determined by calculation. This method is explained in urinalysis.

The urine consists of a great number of substances varying in their nature. Some being excreted just as taken in the food, others being the result of certain changes which the food has undergone in the alimentary canal, the tissues, and the kidneys. These constituents are:

(1.) WATER.—The solid matter in the urine consists of about 4 per cent. The solid matter varies with the specific gravity, every degree in the urinometer representing about 2.33 of solid matter per thousand. Water passes out of the body through the lungs, the skin and the kidneys. The amount excreted through the skin and kidneys being in inverse ratio to each other, that is when a great quantity is lost through the skin a very small quantity passes through the kidneys. The large proportion of water eliminated from the body is through the kidneys, the blood continually loosing water in this way.

(2) INORGANIC SALTS.—These salts exist mostly in their natural condition. These consist of chlorides, phosphates, and sulphates of the alkalies and alkaline earths. They rise partly from the salts taken in food and partly from the metabolic changes in the body chiefly in connection with the proteids.

Sodium chloride is the most abundant, amounting to about 1 per cent in normal conditions derived chiefly from salt taken in food. Hydrochloric acid is united with sodium, a normal adult excreting about 20 grams of sodium chloride. The amount depends on the food and also upon the normal or abnormal conditions of the body. In inflamation, as the crisis is reached, the amount is increased. Chloride of calcium, chloride of potassium, phosphate of lime, and chloride of magnesium together with sulphates are also found in small quantities. Phosphoric acid in the urine is united with the alkalies and the alkaline earths. Of this phosphoric acid about 2 to 3 grams are eliminated daily by a normal adult. The phosphates arise chiefly from phosphates of the food and the destruction of tissues containing phosphorous. The sulphuric acid in the urine is united with potassium and sodium constituting sulphates and also in union with the phenol and indol-oxyl sulphates of potassium, the sulphates being combined chiefly with organic substances, About two grams of sulphuric acid are eliminated daily by healthy adults. Carbonic acid is found in urine, as carbonate of sodium or combined with magnesia and calcium, In this case if a few drops of nitric acid is added, the urine will seath, this effervescence rising from the presence of CO_2 . Lime is found in the urine almost entirely in union with phosphoric acid and oxalic acid, the amount varying within small proportions. Ammonia is found in the urine in nitrogenous form, yielding ammonia, the amount depending on the food, being larger in the mixed diet than in a vegetable diet. Magnesium, in the phosphate form, iron, and nitric acid exists in very small quantities in the urine.

(3) GASES.—These gases consist of CO_2 about 17 volumes per cent, N about one volume per cent and O about .1 volume per cent, although the O is present only in very minutes traces. Carbonic acid is found loosely combined with the acid phosphate of soda.

(4) PIGMENTS. Urine is always colored. McMunn claims that urobilin is always present in urine normally, although small in quantities. The pigments of the urine are not very satisfactorily known. This is increased by the fact that chromogens exists in the urine, that is the substances giving rise to pigments by oxidation: the urine pigments are at least two in number, urobilin and indigo from indican. The exact nature of the yellow coloring matter is uncertain. The urobilin does not give the yellow color to normal urine. Urobilin or hydro-biliruben which is formed from biliruben is sometimes present. In the intestines, part of the bile pigments is converted to hydro-biliruben which is absorbed and eliminated by the kidneys as urobilin. There is also indican or indoloxyl, sulphates of potassium which is believed to be produced in the alimentary canal and which on oxidation, yields various indigo pigments. On decomposition indican produces leucin and indigo, both blue and red. Indigo blue may be obtained from normal urine in small quantities. Uro haematin is found in urine of rheumatic cases and in Addison's disease. Skatoloxyl, sulphate of potassium, uro chrome and uro melanin may also be found in small quantites in urine but these are not normally present as pigments.

(5) NITROGENOUS ELEMENTS —Aside from the special nitrogenous substances introduced along with the food the principle nitrogenous elements are urea from two to three percent and uric acid about .05 per cent. Small quantities of substances related to urea are also found. Kreatinin, hypoxanthin, hyppuric acid, oxaluric acid and sulphocyanides. These nitrogenous matters result from changes in the proteid substances and allied substances like gelatin in connection with the body metabolism.

(6) ALBUMIN.—Is is claimed that normal urine always contains albumin.

This, however, is not accepted, by all. There are found, however, ferments in the urine. If a large amount of alcohol is mixed with urine, there is thrown down, a precipitated, containing phosphates and several substances, in small quantities. The ferments are found to be amylolytic and proteolytic if the ferments are entangled in fibrin by washing out, ferments may be secured that will convert starch into sugar and if hydrochloric acid is added the pepsin will be found. From this it has been concluded that some of the alimentary ferments escape into the urine.

(7) NON-NITROGENOUS ELEMENTS.—Small quantities of various acids are found. Oxalic acid appears as the oxolate of lime when rhubarb, apples, tomatoes, etc., are used as food and in small quantities with any kind of diet. Lactic acid, butyric acid, formic acid, acetic acid and it is also said glucose in minute quantities are present normally in the urine. The amount of these various substances found in the urine vary considerably in different individuals and in different periods of life.

ABNORMAL URINE COMPOSITION.

There are some substances found in the urine under abnormal conditions the exact nature of which and the means of discovering them being discussed in urinalysis. Among these we find serum-albumin, and serum-globulin, haemi-albumoses, peptones, pepsin, haemoglobin and fibrin, the latter being identified in its fibrillar form by the microscope. In addition to these albuminous substances, sugar, bile pigments, bile salts, mucin, epithelium from the bladder or kidneys, or the urinary passages, pus cells and red blood corpuscles may be found. Corpuscles may be detected by the use of the microscope. In addition to these, there are found at times, casts consisting of cylinders of epithelial cells or fibrinous casts, formed out of matter in the lumen of the tubules. The urine may be milky on account of the chylous matter in the form of globules present in it. This is common in very warm climates and said to be due to parasites in the blood. Various substances such as carbolic acid, salicylic acid, iodine, bromine, etc., may be found in the urine. There are various kinds of urinary deposits, the exact nature of which is detected by the use of the microscope.

(1) These are found in connection with the urine when acid, for example, uric acid, found either free or in the form of urates. These urates are the most common form of the urinary deposit, forming a heavy precipitate when the urine is cold. The chief urates are those of sodium, potassium, and ammonia. In addition to these we find phosphates, crystals of oxalate, lime, tyrosin and leucin.

(2) Certain deposites are found in connection with the urine when alkaline, such as the triple phosphates always found in the urine when ammoniacal, lime phosphates, acid urate of ammonia, which is always found in alkaline urine.

(3) In addition to these certain forms of organized deposits are found. Spermatozoa, bacilli, bacteria, etc., may be detected by the microscope. Mucus may be found in fiber form mingled with cells of epithelium from the pelvis, bladder, ureter and kidneys.

Blood may be found in the urine and if it is found there is always present albumin. Various forms of casts may also be found in the urine containing blood corpuscles, oil globules epithelial cells, etc. The chief abnormal constituents of urine are (a) albumin giving origin to albuminuria and (b) sugar, producing diabetes. The different forms of albumin must be determined by precipitation. The two forms however in which they appear usually are

serum-albumin, and serum-globulin. The sugar found in diabetic urine is dextrose in form.

SECTION XIII.—Physiological Characteristics of the Urine and its Constituents.

A large quantity of water, salts and nitrogenous substances is separated by the kidneys. If an animal is fed upon a flesh diet the urine is clear and acid, very abundant in urea, phosphates and uric acid. If the diet is vegetable, as in the herbivora, the urine is not clear, it is alkaline in reaction, is very rich in carbonates and poor in phosphates, instead of uric acid being hyppuric acid. The nature of the diet very much alters the urine; hence, if the diet is rich in alkaline salts the blood is rich in these salts and this influences the urine. In the case of a mixed diet the urine is intermediate in character. Of the water excreted from the body in the human subject about 40 per cent is eliminated by the skin and lungs, and 60 per cent by the kidneys. If the diet is wholly or almost wholly animal flesh the amount of water excreted by the urinary system is increased to 70 per cent. If the quantity of urine is increased the amount of solid matter eliminated will also be increased, urea being generally increased from 3 to 4 per cent. If the supply of water is cut off from the bodily system the amount of urine is diminished normally about one fourth to one fifth. In the case of the use of drugs that are quickly dissolved, the substances in solution may be found very shortly after being taken, in the urine, for example, iodide of potassium.

(1) UREA. The chief organic constituent of urine is urea, N_2H_4CO It is generally regarded as an amide of carbonic acid. The average amount of urea excreted in 24 hours is about 30 to 35 grams. It is the principal nitrogenous waste excreted from the body. It contains about 46 per cent of nitrogen and contains less carbon in proportion to nitrogen than any other organic substance, the result of proteid oxidation. If we know the amount of urea secreted in a given time, we can estimate the amount of proteid destroyed in the process. The quantity of urea excreted depends, principally upon the food and its nature. When an animal is starved the amount excreted is lessened, gradually diminishing until a minimum is reached before death takes place. The formation of urea takes place in the liver and as the blood in the renal vein has less urea than the blood in the renal artery, it is said that no urea is formed in the kidneys. Even after the kidney is extirpated, urea is still found in large quantities in the blood. It is brought to the kidneys for excretion in the blood, the epithelial cells taking it out of the blood and passing it to the tubular lumen for elimination. Containing, as it does, N it must be derived from proteid substances, or rather from the albuminoid tissue elements or from nitrogenous proximate principles of the food. The quantity of urea excreted is not influenced by muscular activity but is distinctly increased when a diet rich in albuminous materials is taken.

Hence, it is concluded (a) that muscle when actively working does not produce nitrogenous waste and that, therefore, its contractile activity is not accompanied by oxidation of its own substance in the form of N, but rather by the burning of certain carbonaceous materials that are deposited in the muscle substances.

(b) A part of the proteid food material is in some way converted into urea. We have seen that the trypsin of the pancreatic juice converts some portions of the proteids in the food substance into leucin, tyrosin, etc. When leucin and tyrosin are introduced into the alimentary canal the amount of urea in the urine is increased, but no leucin appears in that fluid. There is, therefore,

good ground for believing that the leucin formed by the pancreatic juice in the digestive process is at least one of the sources of the urea of the urine. If leucin is present in the alimentary canal it will doubtless be absorbed and carried to the liver in which the urea is found. This substance is not present in the muscular, nervous and glandular tissues of the body aside from the liver. This leads to the conclusion that one of the functions of the liver and also of the spleen is to transform leucin, tyrosin, etc., into urea. This conclusion is strengthened by the fact that in acute atrophy of the liver, a diseased condition, in which the activity of the hepatic cells is seriously interfered with, the urea of the urine is replaced by leucin and tyrosin. We said before that muscle does not by its contraction increase the excretion of nitrogenous waste but the corpuscles which compose muscles, as well as those found in nervous glandular and their tissues are the centers of constant metabolic processes involving changes which imply the formation of certain waste products such as kreatinin, xanthin, etc., which are to be regarded as resulting from the chemical changes connected with the existence and development of the corpuscles. These substances are more or less readily diffusable and will be carried off from the tissues by the blood ultimately reaching the kidneys, but the urine contains very little if any kreatinin. It was once held that the renal epithelium took up the kreatinin and converted it into urea, excreting it as such in the uriniferous tubules It is now known, however, that the extirpation of the kidney leads to the accumulation in the blood not of kreatinin but of urea. From this it is concluded that the formation of urea is not dependent upon or caused by the activity of the renal epithelium. As we have said, there are reasons for believing that the liver is actively engaged in the formation of the urea from leucin. It is concluded from this by analogy that the liver also converts kreatinin into urea. If this is so, then the urea of the urine has a double source, being derived partly from kreatinin formed by the ordinary chemical changes taking place in connection with muscles and other tissues, and partly from the leucin resulting from tryptic digestion of the proteid food stuffs. Both the kreatinin and leucin according to this would be changed by the liver and possibly by the spleen into urea and the function of the renal epithelium would be confined to gathering up the urea so formed from the blood and to the excretion of it into the uriniferous tubules. If the urea and other forms of nitrogenous waste should fail to be separated from the blood as we find in certain renal diseases, their accumulation in the blood and in the body will lead to convulsions and other symptoms grouped under the term aræmia. Liebig defended the theory of the derivation of urea from the muscles. Muscular activity he believed to be carried on at the expense of nitrogenous substances either taken from the food or from the tissues. The food stuffs he regarded as either tissue forming or heat-producing, the former being albumin and the latter carbohydrates and fats. The albuminous matters he claimed was used in tissue upbuilding and in the production of muscular activity. The carbohydrates and fats by oxidation processes were converted into heat in connection with the formation of CO_2 and H_2O in the decomposition of nitrogenous matters urea and uric acid are formed while in the decomposition of non-nitrogenous matters CO_2 and H_2O are formed. If Liebig's theory is true muscular activity would increase the amount of urea and uric acid. Various experiments have been made to test this.

Fick and Wislicenus made an ascent of one of the Swiss Alps. For almost a day before ascending no nitrogenous food was taken, after which they spent 6 hours in ascending. They collected the urine (a.) prior to the ascent, (b.) during the ascent, (c.) 6 hours after the ascent, and (d.) after taking a

meal of nitrogenous food, and (e.) during the following night. The work accomplished in ascending must have depended either upon nitrogenous food or albumin from the body. By estimating the work done and the energy produced by the albuminous materials it was found that less than 1-2 of the energy expended represented energy from the albumin. One gram of proteid is estimated to yield 1-3 gram of urea. Part of the proteid nitrogen assumes other forms as uric acid and kreatinin so that we cannot acurately determine the proportion. This indicates that the urea did not correspond in any sense with the wasts of the muscles. It was found that by the use of nonnitrogenous foods there was a diminution of N excreted both during the ascent and the period of rest and by the use of nitrogenous food the amount of nitrogen excreted increased. The amount of work done in the ascent was much in excess of the nitrogenous changes measured by the excretion of urea. These muscular changes depend, therefore, upon the metabolism of carbohydrates and fats and not upon the changes taking place in connection with nitrogenous food alone. This view has been confirmed by others who have shown that muscular exercise involves the increase of CO_2, a fact that depends upon the use of carbohydrates and fats in connection with muscular exercise. In addition it is found that there is found in connection with the muscles only very small traces of urea. This amount not being increased by muscular effort or exercise and no increase taking place in the amount of urea circulating through the muscle. These points seem to negative the theory of Liebig as to the muscle formation of urea leaving the liver as the chief if not the only source of urea

Cyon made several experiments in transfusing blood through fresh liver at the temperature of the body finding an increase in the amount of urea after transfusion, some urea may have been washed out which already existed in the liver but even in this case some must have been formed as there was an increase from .08 to .176 grams of urea.

Shroeder experimented upon the liver of a dog when fasting and during digestion. He found that in the former condition by the transfusion of blood no urea increase was found, while in the latter condition there was an increase amounting to nearly 30 per cent. In addition to this it has been found that when the liver becomes atrophied urea disappears altogether from the urine. Liebig concluded that in the dissociation of albumin in connection with the tissues urea was formed. Experiments by various physiologists have negatived this theory, the amount of urea found in muscles being very small and muscular activity not tending to increase the amount of urea. The amount of carbonic acid is increased by muscular activity, the muscular energy being derived from the nonnitrogenous food elements more largely, than that derived from nitrogenous food elements.

How is the urca formed? It is closely connected with the ammonia group and by the process of hydration, is easily changed to ammonia carbonate. It arises from the proteids by hydrolysis and oxidation, in which ammonia compounds are formed, being carried to the liver and changed to urea.

Drechsel found that cobamic acid was found in the urine of dogs and that ammonium carbonate could be converted into urea by deprivation of a molecule of water. According to him there are three processes. (a) Oxidation resulting in the loss of H. (b) Reduction in the loss of O and (c) dehydration resulting in the loss of water, the result being the production of urea. As the ammonium carbonate exists in the body, he claims that in this way urea is produced. It has been shown that by removing the liver of dogs the urea is decreased and the amount of carbonate is increased. It has been found recently

that the amount of ammonia in the blood of the portal vein is three or four times that in the arterial blood, normally. It is claimed that these ammonia compounds are converted into urea in the liver so as to protect the arterial cirulation. If the liver becomes deranged a large amount of ammonia is found in the blood and produces fatal results. This amount of amonia seems to arise from the decomposition of proteids in the stomach glands and pancreas during the act ot secretion. The ammonia carbonate arises originally from the proteids and albuminoid foods, Drechsel thinks these are subjected to hydrolysis forming leucin, tyrosin, etc. These substances are then oxidized in the tissues forming CO_2, H_2O, and NH_3, the CO_2 and NH_3 uniting to form ammonium carbonate which passes to the liver and forms urea. This forms the basis of the carbonate theory of Drechsel in regard to the formation of urea. Urea is found even after the liver is removed. Some of the ammonia compounds found in other body tissues may be changed to urea in other parts of the body, Drechsel has produced urea external to the body by boiling the proteid with an acid. He used hydrochloric acid. In order to maintain the hydrogen evolution and keep out O from the air he mixed it with metalic zinc. In this decomposition he found lysatinin which when isolated in connection with barytan water produced urea. According to this, urea was obtained by decomposition and as the lysatinin is found in the body it is possible that the same process goes on in the body iu the formation of urea. In addition to what we have said as to the formation of urea in the liver, it is found that in the case of phosphorous poisoning the amount of urea is greatly decreased and that by destroying the blood corpuscles and freeing hæmoglobin in the blood the amount of urea is largely increased.

Noel-Paton has shown that the bile secretion and the urea formation are directly related to each other. Therefore, he concludes that the chief source of urea formation is the destruction of the red blood corpuscles in the liver and in the spleen.

(2.) URIC ACID. It is found constantly in the urine but in smaller quantities than the urea. It is closely allied to urea and is a result of the same metabolic changes. It is a more complex substance than the urea, one of the uric acid molecules dividing into two molecules of urea and oxalic acid. Next to urea the most important element in the urine is the uric acid, about .5 to 1 gram per day normally, chiefly in combination with kreatinin and xanthin are excreted. In birds and reptiles it is the chief nitrogenous element taking the place of urea as the chief product of proteid metabolism. It is probably produced in the same way as urea as it is increased by a diet rich in albuminous materials. It occurs in such small quantities in the human subject that it has not been investigated as yet. It is sometimes regarded as an intermediate stage in the metabolic changes in the proteids which immediately preceeds urea. It has been suggested that on account of the close relation of uric acid, to xanthine and hypoxanthine the uric acid is produced from these by oxidation.

Harbacewaky has shown this in the lymphoid tissne including the spleen, there is a substance from which uric acid is formed. He thinks that uric acid represents a product of metabolism in connection with white blood corpuscles, as urea does in the case of red blood corpuscles. The close affinity of uric acid and urea is brought out by the fact that uric acid takes the place of urea in birds and reptiles and is produced in the liver. If the kidneys are removed in the case of birds, uric acid accumulates in the blood indicating that the kidneys do not produce the uric acid. The removal of the liver, however, leads to the diminution of uric acid, ammonium salts taking its place. From this it is concluded that the proteid metabolism produces ammonium salts which are

carried by the liver and therefore transformed into uric acid. Uric acid can be produced from urea and glycocol. In the human subject ammonium salts are found in the urine in cases of liver atrophy and phosphorous poisoning.

In certain physiological conditions such as fevers and leucocythemia there is an increase of uric acid. This last confirming the view of the formation of uric acid in connection with the white blood corpuscles. In human urine it exists not as a free acid but as an acid salt in combination with potassium and sodium, ammonium and calcium. These salts are soluble in urine but when the urine cools they deposit as urates, later forming the uric crystals. Closely connected with uric acid we find several nitrogenous substances with the xanthine family which are found in the urine in very small quantities. They representing a certain amount of proteid metabolism, but what amount or what kind of metabolism they represent is not yet known. If uric acid accumulates in the system it may give rise to gout or when excessively found in the urine may form renal or vesical calculi.

In connection with the waste of nervous and muscular tissue kreatin is formed. Closely related to it is kreatinin which is formed in the kidneys being always present in the urine. Kreatinin is not formed in the blood so that the change from kreatin to kreatinin does not take place in the blood so that it is probably transformed in the kidneys or at least in the urine as it is collected in the kidneys Kreatinin occurs in urine in the human subject to the extent of about one gram daily. It is closely connected with kreatin, being kreatin in hydrated form which is a constant element in muscle, being separated from muscle food and eliminated as kreatinin. It is partly derived from muscle food and partly from metabolism in the body tissues. Urea is not found in connection with the muscles, while kreatin occurs in large quantities, this large quantity being transformed according to some into urea and also into kreatinin. Hyppuric acid is found in place of uric acid in the urine of herbivora. Hyppuric acid is a benzoil amido acetic acid. It is always found in very small quantities in human urine to the extent of .5 grams daily. If a vegetable diet is used this amount is increased. If benzoic acid is fed to animals hyppuric acid is found in the urine, the benzoic acid uniting with glyceral in the kidneys. The vegetables yield benzoic acid, and hence the increase of hippuric acid in the urine. The small quantity, however, found in the urine normally, must arise from the proteid metabolism probably as a product of proteid decomposition, especially in the proteid putrefaction in the large intestine In addition to these, sulphur is excreted in the urine in the form of ethereal salts with compound aromatics. Phenol, indol, skatol and cresol are formed in the large intestine in connection with the decomposition process, part of these being eliminated in the fæces and part in the blood absorption being carried through the liver where they are united with sulphuric acid forming sulphates which are excreted in the urine. Tyrosin is also occasionally present in the urine. (3) The aromatic substances of urine are absorbed from the small intestine and excreted through the kidneys. These arise from the decomposition taking place in albuminous materials in connection with the pancreatic juice. In constipated conditions they are found in the urine on account of the large increase in the system. Urobilin found in the urine is derived from biliruben which results from the hæmoglobin decomposition in the liver. Indican is probably derived from indol which arises from the putrefaction taking place in the large intestine under the influence of a micro-organic ferment. The saline matters depend upon the salts in the food. The chloride of sodium is the necessary element in the urine excretion. If it is withdrawn from the food supply the amount excreted is diminished and a minimun quantity con-

tiuues to be excreted till death results. Phosphates are derived from the food elements and from the tissue metabolism. Sulphates arise from the albuminous decomposition.

Various physiological phenomena have a bearing upon the urine. In the case of a child, the amount of urine is much larger in relative proportion to size, also a larger proportion of urea and salts. In old people, the amount of uriue is decreased aud the solid substances are also diminished. The male excretes more urine than the female and the male urine is more fully supplied with solids. During sleep the urine accumulates, being more solid and having more of the pigments and acids. The excretion in connection with the skin uses up more of the water so that the solid matters are increased. The phosphates being increased and the other solid substances decreased. During pregnant conditions the urine becomes deeply colored and manifests a greater density due to the presence of triple phosphate crystals, particles of fat and fungus organisms.

SECTION XIV.—Mechanism of the Excretion of Urine.

The kidney is a compound tubular gland the ultimate terminations of the tubules; the glomeruli being lined by a layer of single squamous epithelium while the other parts of the glandular tract, for example, the convoluted tubes have an epithelium which is much more distinctly of a glandular character and which, from the shape and appearance of its cells we should expect to be engaged in the separation of materials from the blood. The blood reaches the kidneys through the renal artery immediately upon the arterial system, the branches of which pass into the substances of the kidney and by dividing ultimately form the afferent vessels to the glomerulio. In each glomerulus, the afferent vessel breaks up into capillary loops which being reuniting from the efferent vessel. This being of smaller calibre the afferent; hence, the blood in the glomerulus is at a considerable pressure and the rate of the flow is slow. Under the influence of this pressure water containing highly soluble and diffusible salts in solution filters through the walls of the capillary loops of the glomerulus and the epithelium covering the glomerulus into the Bowman's capsule. From thence it passes into the uriniferous tubules. The effereut vessel after leaving the glomerulus breaks up into capillaries which are distributed over the surface of the convoluted tubules and it is believed that the large epithelial cells in these tubules extract from the blood iu the capillaries, certain substances, the nitrogenous matters and perhaps also pigments and excrete them into the uriniferous tubules. As the blood passes through the organs certain matters are lost which constitue the urine which after secretion in the kidneys is transferred by the ureters to the bladder. This waste may take place by a transudation from the blood by the active secretion of the epithelial cells or by both of these processes. The process of secretion is dependent upon blood pressure. Increase in blood pressure producing au increased secretion. If the renal circulation becomes too slow indicating a great fall in blood pressure the secretion is arrested. Severe loss of blood decreases the secretion, the increase of aortic pressure causing an increase and the decrease of aortic pressure, a decrease of the secretion. Hence, that process by which the urine is separated from the blood by the kidneys may be said to consist of two parts. (1) A filtration process in Bowman's capsule by which a large quantity of water with certain solid salts in solution is rapidly removed from the blood. (2) A true excretory process. The epithelium of the convoluted tubules by its vital activity separates uitrogenous and other matters with some water from

the blood. The process of filtration must necessarily be dependent upon and must largely be influenced by the blood pressure in the smaller arteries in the kidneys, for the flow of urine ceases when the pressure in the uriniferous tubules is greater than the pressure in the blood vessels, for example, when the ureter is ligatured. If the pressure in the renal artery is decreased the urine secretion is diminished. The rate of secretion depends upon the difference in pressure between the renal arteries and the urinary tubules. The secretion is dependent upon the difference in pressure between the vessels of the kidneys and the ureter. By the increase of pressure in the kidney the urine secretion is increased. The filtration process is not to be regarded as identical with ordinary filtration through dead materials, for the cells of the capillary walls and those of the epithelium covering the glomeruli undoubtedly exercise some influence in determining what substances shall pass through them. On the other hand, the secretory process is only influenced in a secondary degree by the blood pressure, being dependent on the activity of the cells lining the convoluted tubules and these cells are, as far as known, stimulated to their activity by various substances contained in the blood. The condition of the blood influences the secretion. The Malpighain bodies are so arranged structurally that the pressure in the glomeruli is great and the blood flow is slow. Thus, the water, salts and albumin will be separated from the blood by filtration and collected in Bowman's capsule. An increase in the amount of water used for example, by profuse drinking, increases the excretion of water by increasing the blood pressure. The pressure theory of itself is insufficient to account for the secretion. While the blood is alkaline, the urine in the human subject is acid. There is also a larger proportion of urea and salts in the urine than in the blood. Certain of the substances found in the urine are not found in the blood for example kreatinin, as the urine differs in its character from the blood, it cannot be simply a transudation from the blood. If the renal vein is compressed or ligatured, the pressure in the glomeruli will be increased but the amount of urine will be lessened. According to Ludwig the blood pressure causes the transudation of the blood plasma through the capillary walls of the glomeruli. After this the fluid is brought into contact with the epithelial lining of the tubules and into connection with the lymph around the tubules, the water is then reabsorbed by the lymph and also into the blood capillaries.

If we take account of the glandular character of the epithelium of the tubules and assume that the cells are active then we can account for the difference between the urine and the blood as to the matters found in the two fluids especially the fact that certain substances are found in the urine that are not found in the blood. Certain substances are found in the cells indicating the cell activity, for example the crystals of uric acid. It seems to be not so much, a question of blood pressure as of the velocity of the blood flow together with the existence of certain substances such as O, urea, and the salts, which assists the secretory process by acting within the cells. The rapid rate of the flow assists in the secretion of the urine by bringing these substances into close contact with the cells and inducing activity upon the part of the cells. The secretory process, therefore, takes place in connection with the cells, urea, uric acid, and salts, being first secreted in these cells, these being washed out by the water which is filtered in connection with the glomeruli. The cell activity, however, in reference to these substances depends upon the rapidity of the blood flow and upon the amount of water found in the blood. An increase, therefore, of the water or of the velocity of the blood flow will increase the urine secretion. The blood pressure in the small vessels of the

kidney will be increased (1) by the general increase of blood pressure due to the increased force or frequency of the cardiac contractions or to the contractions of the smaller arteries all over the body. (2) By the contraction of the small arteries in reigons outside of the kidneys, for example, the skin, the intestines, etc. (3) By the relaxation of the renal artery or its main branches. The opposite conditions will of course, diminish the blood pressure in the smaller renal vessels.

SECTION XV. Innervation of the Kidneys.

The actions and influences of the central nervous system upon urine secretion and excretion is not well known, as very little investigation has been made in connection with the minute nerve connections of the kidneys. The exact nervous tracts along which particular impressions travel to the vessels of the kidney are not definitely known. The nerves to the kidney come from the renal plexuses and the smaller splanchnics. Some fibers have been followed into the papillæ. The section of the spinal cord below the medulla lessens or causes to cease altogether the flow of urine. This is probably due to the great fall of blood pressure produced in the vessels of the kidneys in connection with vaso-motor paralysis. If the lower end of the cord after division is stimulated the blood pressure rises in the vessel of the kidney as well as the body generally, and the urine secretion is increased. The higher centers have an influence upon the urine secretion and excretion. Emotional conditions increase both the secretion and the excretion. The central source of the renal nerve is found in the floor of the 4th ventricle close to the vagi roots. If the medulla is punctured in this region the amount of urine is increased and it is found to contain albumin and blood-serum. The section of the renal nerves leads to polyuria and the specific gravity of the urine becomes lessened. The same result to a less degree follows the section of the splanchnic nerves, a fact to be explained in connection with the dilatation of the renal artery. The splanchnic contains the fibers of the vaso-motor nerves from the 1st dorsal. The renal vessels and those in the intestines become paralyzed. On the other hand, stimulation of the distal portion of the divded splanchnic nerve causes contraction of the renal artery and a diminution or complete arrest of the flow of urine.

The kidney, like the spleen, is subject to rythmic variations. The kidney diminished in size when the renal arteries contract increasing when the vessel calibre increases. The tracings that mark the increase in the renal volume indicate that the changes follow the respiratory and cardiac pulsations. Vaso-motor action influences the change in the size of the kidney, for example, an excessive supply of blood to the vaso-motor center area produces vaso-motor stimulation, causing diminution in the volume. There are no vaso-dilator fibers to the kidneys as the stimulation of the splanchnic branches of the sympathetic causes diminution in the renal volume. There is an intra-renal nervous arrangement, although it is not as yet completely understood. If water and urea are injected into the blood there is a contraction of the kidneys followed by dilitation. The same results follow when all nervous connection is cut off from the central nervous system.

Mosso in his experiments introduced the actheter into the bladder and connecting it with a recording instrument to discover the volume of the bladder. He found that the bladder could be entirely emptied without the use of the abdominal muscles. He claims that the feeling of fullnes and the desire to urinate, results from the stimulation produced by the presence and pressure

of the urine. The bladder is very sensitive, constant changes taking place under reflex stimulation, the pressure of the bladder depending on reflex stimulation as much as on the amount of urine present. It is this that causes the desire to urinate under psychic influences. This may pass away by the action of the sphincter urethrae until some new reflex stimulation produces this desire to urinate again. The longitudinal and the circular coatings of the bladder have distinct nervous connection. If stimulation is applied to the sacral nerve branches it produces strong vesical contractions of the longitudinal coating in the case of the dog. If the sacral nerves are stimulated on the one side there is a contractions of the bladder only upon one side. This has led to the conclusion that the longitudinal coating of the bladder is regulated by the sacral nerves. If the hypogastric nerves which have fibers from the dorsal and upper lumbar region of the cord, are stimulated, it produces vesical contractions chiefly in connection with circular fibers at the neck of the bladder. Thus, it is concluded that the hypogastric nerves regulate the circular fibers in contracting to evacuate the bladder. Micturition when viewed in general seems to be purely voluntary. By voluntary action the bladder muscle fibers become contracted, relaxing the sphincter exterus by the inhibitoin of the spinal center, contracting the abdominal muscles and the ejaculator urinæ muscles, resulting in the distruction of urethral resistance and the flow of urine. This, however, does not explain certain facts in connection with micturition. (1) In the case of the dog when the lumbar region of the spinal cord has been entirely severed from the dorsal region, micturition is not destroyed. There is no voluntary effort in this case. All the micturition process therefore, must take place reflexly. When the bladder is filled stimulation applied mechanically to the abdominal walls or to the anus will completely empty the bladder. The ejaculatory muscles contracting, producing rythmical increase in the flow of urine. This has led to the conclusion that there is a center of micturition in the lumbar reigon of the spinal cord subject to stimulation. This center in the human subject is found also in the cord above the center that regulates the genitals. That this center is one of reflex action has been proved in connection with the bladder. The bladder pressure is subject to great changes. Not only do we find changes in pressure accompanying the respiratory action but we also find active variations produced reflexly causing sufficient stimulation to evacuate the bladder. (2) When the urethra is obstructed so that the full bladder does not produce sufficient stimulation to empty it, there are found numerous and powerful contractions of the vesical walls which are purely involuntary. These, while insufficient to empty the bladder, produces great pain sometimes. As the tension increases the fibers become more actively contracted. In this way the simple distention of the bladder aside from any involuntary effort may give rise to strong contractions sufficient usually to empty the bladder, but in cases of obstruction, insufficient to empty the bladder but producing rythmical contractions. From this it is concluded that micturition is not purely voluntary. In confirmation of this it is found that micturition is involuntary in certain abnormal conditions where the spinal cord is paralyzed or injured in some way. The same is true of micturition resulting reflexly from sensory stimulation. The afferent impulses in this case pass to the center in the spinal cord. The same thing is true in the case of emotions producting micturition. In both cases the impulses pass from the brain, along spinal nerves to the spinal centers, producing micturition reflexly through the micturition center. Thus. the action is not direct upon the bladder walls but reflex through the micturition center. This idea is not disproved by the fact that when the bladder is paralyzed

this is taken as the symtom of cerebral or spinal diseased conditions. The real reason is the effect produced upon the micturition center, either destroying its action or weakening its force. In cases in which we find an irregularity in micturition particularly in children, the cause is to be sought in the excitement on the reflex center in the spinal cord, under slight stimulation, where incontinence arises in connection with spinal or cerebral diseased conditions, it depends upon the weakening of the activity of the spinal centers, so that instead of a complete emptying of the bladder there is a constant dripping of the urine. The spinal nerve center or centers that regulate the innervation of the bladder are situated in the lumbar region of the spinal cord.

According to Goltz between the 2d and 5th lumbar nerves, the sensory fibers from the bladder and urethra pass into the cord through the posterior roots of the 1st, 2d, 3d, 4th, and 5th chiefly, the 2d and 3d, spinal nerves in sacral region. If these fibers are stimulated they excite reflexly the motor fibers to the bladder in the anterior roots of the 3d and 3d, spinal nerves.

The motor nerves regulating the muscles of the urethra and the Sphincter urethræ leave the cord through the anterior roots of the 2d, and 4th spinal nerves in the sacral region. The bladder gets motor fibers, according to Langly from the fibers of the 2d, 3d, 4th, and 5th lumbar nerves, passing to the bladder through the sympathetics, hypogastrics and inferior mensenteric ganglia and also from the 2d and 3d spinal nerves in the sacral region. The stimulation of the former produces a weak and of the latter a strong contraction of the bladder. This center in the lumbar region of the cord is connected with the cerebrum by fibers which are inhibitory. It is said, also by some that nerve fibers pass immediately from the brain through the cord to the sphincter urethræ, bringing it under the control of the will. Some sensory fibers reach the bladder through the hypogastric nerves. the stimulation of these resulting in the reflex stimulation of the motor fibers in the other, hypogastric, resulting in the contraction of the bladder the reflex taking place through the inferior mesenteric ganglion. Here we have a peripheral ganglion acting as a reflex center. When the urine is voluntarily voided this higher center sends down impressions to the voluntary muscles which control the sphincter. Others say that impulses from the higher centers must pass through the spinal center. There are also vaso-constrictor fibers but their course and action are unknown. It the spinal cord is injured procucing irritation higher than the lumbar centers the distension of the bladder takes place, the urine being retained, sometimes passing from the urethra by drops. When micturition is voluntary a a little urine passes into the urethra arousing sensory stimulation which excites the spinal centers. This spinal center is constantly active normally securing the firm closure of the neck of the bladder and preventing the escape of the urine. When the sensory impulses reach the center it is inhibited and as a result the neck of the bladder yields the impulses from the center being conveyed to the bladder and the abdominal muscles resulting in micturition. Similarly, certain psychic influences from the brain affect micturition under the control of the will, although it is objected to this psychic influences that it seems to overbear the normal tonic condition of the spinal center. It is in this way explain influences coming to the spinal center from any part of the body affecting micturition, and producing micturition involuntary ejection of the urine.

SECTION XVI. Micturition.

The excretory organs consist of the ureters, the bladder and the urethra. The urine is being continuously separated from the blood, being secreted con-

tinuously. There may be variations in the flow in normal conditions but it never ceases as the suspension of renal activity results in the urine suppression and produces death quickly. Small currents pass along the tubules that collect the urine, these currents passing from the orifices of the excretory tubules into the calices and are collected in the renal pelvis. It is then carried along the ureters partly by pressure, partly by the force of gravity and partly by peristaltic contractions of the muscular walls of the ureter and is then discharged into the bladder. It is then ejected from the bladder through the urethra. When collected in the bladder its regurgitation into the ureter is prevented by the oblique manner in which these tubules perforate the walls of the bladder and by the small valves formed by the vesicle mucous membrane at the orifice of each ureter.

If one of the ureters in the living animal is laid open and subjected to stimulation at a point along its path peristaltic waves may be seen originating at the point of stimulation and passing to the kidney and the bladder. Even when there is no stimulation applied artificially there are waves peristaltis sometimes regularly and sometimes irregularly, these peristaltic contractions all moving in one direction from the kidney towards the bladder the force and frequency of these contractions depending upon the urine excretion and secretion. That these contractions do not depend upon the presence, or action of urine, however, may be shown by the fact that these contractions occur when the kidney and ureter have been taken out of the body. These contractions seem to be of a muscular character and also rythmic originating in the muscular coating of the ureter just as we found the muscular cantractions of the heart. These do not depend upon nervous connections as when a portion of the ureter is entirely isolated at the center of the ureter in which no nerve connection exists, these contractions are found to take place. While these contractions are not caused by the urine secretion, they occur with greater frequency when the urine secretion is active, indicating that the degree of peristalsis of the renal pelvis and the ureter depends upon the secretion of the urine.

There are three layers in the walls of the ureter, the intimia consisting of a mucous coating inside of which is a muscular coating and outside a fibrous coating; connective tissue fibers constitute the tunica propria of the mucous membrane in the midst of which are found cellular elements, the tunica propria passing into a submucous coat. The tunica propria is covered with stratified tesselated epithelium In the pelvic portion of the kidney there are racemose glands and also in the upper portion of the ureter. The muscular layer consists of two fiber coatings, the external being circular and the internal longitudinal. In the lower portion of the ureter there is a third layer outside of the other two, consisting of longitudinal fibers. The same layers are found in the bladder. Small racemose glands are found in the tunica propria of the fundus. The muscular coating consists of an internal and external layer of longitudinal fibers with a middle layer of circular fibers between them.

Nerve fibers pass to the muscular fibers of the pelvis and ureter and in the bladder there are also groups of ganglia. In the female uretha we find a mucous membrane whose tunica propria consists of delicate connective tissue with numerous capillae chiefly at the external orifice. It is very vascular and contains a number of racemose glands. In the male urethra there are some differences. The epithelium of the prostatic portion is like the epithelium of the bladder, while in the membraneous portion it becomes stratified cylindrical epithelium and in the cavernous portion the simple cylindrical epithelium. The flat stratified epithelium exist in the fossa navicularis. Probably the

urine is driven through the ureter by peristaltic contractions of the walls. It rapidly flows from the pelvic portion of the kidney into the bladder and the bladder is slowly filled as the external orifice is closed. The muscular fibers of the walls of the bladder are kept in a constant state of tonic contraction, the degree of contraction varying at different times. When the bladder becomes emptied contractions of the bladder take place and it becomes folded. As it gradually fills again it is distended, and the fluid that is being collected being held in the bladder by the resistance that arises in connection with the elastic fibers in the urethra walls closing the urethra. If the spinal cord is intact even a pressure of twenty inches of water will be sustained, whereas, if the lumbar region of the cord is destroyed the pressure that can be sustained is very much lessened. This points to the fact that urine is prevented from passing out of the bladder by the muscular tonicity which is preserved by the nervous connection with the lumbar region of the spinal cord. This nervous action bears upon the circular fibers chiefly forming the sphincter vesicae. These fibers are continuous with the circular fibers of the bladder and probably they contract after the other circular fibers of the bladder, completing the emptying of the bladder. Hence the resistence to the outflow of urine depends upon the tonicity of the muscular fibers round about the prostatic portion of the urethra, forming the external sphincter vesicae of Henle. When in consequence of the accumulation of urine a certain amount of tension is caused upon the bladder wall the amount of urine necessary to do this being in inverse proportion to the degree of tonic contraction of the muscular fibers. Contraction of the muscular fibers is set up probably by a reflex action and this assisted by the contraction of the abdominal muscles, drives the urine with force into the urethra the sphincter vessicae relaxing or contractions, being overcome. The urine cannot be driven up the ureters by bladder force. The ureter orifices being slanting, strong pressure tending to close and keep them closed. After the bladder has reached a certain limit of tension the nerves in the bladder walls are stimulated. If the distension increases the muscle fibers of the Sphincter become contracted by reflex action, the expulsion of the urine being closely associated with the escape of a few drops of urine into prossattic portion of the urethra. When the bladder is full there arises a desire to urinate, this desire being produced, as some say, by the passage of a few drops from the bladder into the urethra. This sensation becomes conscious and reruts in an effort during which the bladder is contracted by peristaltic action, the urethral resistance being overcome and the urine flowing freely through the relaxed sphincter vesicae. When we speak of the bladder as full we do not mean necessarily filled with urine, as the desire to urinate may exist where only a small quantity of urine is in the bladder. There is a continuous tonicity in the bladder, although this tonicity varies considerably. If the tonicity is great the increased contraction may produce the desire to urinate with only a small quantity of urine and if the tonicity is small a large quantity of urine may be necessary, hence the desire to micturate depends upon (1) the condition of tonicity in the bladder and (2) on the amount of urine found on the bladder, the tonicity depending upon nervous regulation. It is certain that a free flow of urine follows this occurrence as it passes along the urethra, the last portions of the urine are thrown out of the urethra in drops. This being caused by the irregular muscular contractions of the bulbo-cavernous portion of the urethra, the contractions pressing upon the urethra.

Englemann has carefully studied the ureter movements. The contractions of the muscular coating consisting of an internal longitudinal and an external circular layer takes place spontaneously at varying intervals of 10 to

20 seconds, in the case of the rabbit commencing at the kidney and moving towards the bladder along the ureters as a peristaltic wave. By this peristaltis the urine is driven into the bladder intermittently. Observations have been made in the human subject which confirm the view in cases where there was found a misplacement of the bladder. Englemann found that by artificially stimulating the ureter at a particular point, peristalsis was produced in both directions. In the absence of ganglia he concluded that the peristalsis originated in the muscular coating. The wave passing along the muscle just as in the transmission of contraction along the muscle fiber. The originating cause of the stimulation of the ureter is found in the accumulation of urine in the upper part of the ureter next to the kidney, stimulating the muscle to contraction. Difference of opinion exist as to whether the contractions take place spontaneously, or requires stimulation of the urine. Englemann found that by dividing the ureter near to the kidney, the contractions in the part attached to the kidney continued. This seemed to indicate that the contractions result spontaneously from the muscular tissue. When thus originated there is a definite knowledge of the contractions and of its action in forcing the urine through the ureter.

In the bladder we find a muscular coating of two layers, one internal circular and the other external longitudinal. There is also a longitudinal layer in the interior of the circular coat. There is not the same distinction between the layers that is found in the intestines forming a single continuous layer. The circular layer is stronger at the cervical end forming a sphincter in connection with the urethral opening, called the internal sphincter vesicæ. Outside the bladder there is a muscular coating forming the sphincter urethræ. When the urine reaches the bladder it is kept inside by the elastic action of the portion at the urethral opening and the tonicity of the sphincter vesicæ. As the urine accumulated the sphincter urethræ comes into action. The sphincter uethræ is under the control of the will, although normally it is subject to reflex action. Regurgitation of the urine is prevented by the curved course of the ureters through the bladder walls, the pressure of the urine closing the ureters. When the bladder is filled there is excited sensation corresponding with the filling of the bladder and the desire to urinate followed by micturition. Micturition consists of the bladder centraction accompanied by the relaxation of the sphincter urethræ resulting in the forcing of the urine out into the urethræ. This contraction is very strong and it is assisted by the contraction of the abdominal walls, producing an increased abdominal and pelvic contractions assisting in emptying the bladder. Much difference of opinion exists as to the cause of these contractions of the biadder and the abdomen. When the bladder is filled, sensory fibers in the bladder are stimulated reflexly by contracting the muscular coating in the bladder and driving out some urine into the urethræ. By the passage of these drops of urine into the urethræ another stimulation is aroused producing the desire to urinate. Thus, the will adds its force to the musculatnre of the bladder. The bladder may be prevented from being emptied by the voluntary contraction of the sphincter urethræ, if the bladder is not overfilled. If it is, then the voluntary control is limited to the abdominal muscles and sphincter urethræ, the normal bladder contractions being involuntary and reflex througe the center of micturition in the lumbar region of the cord. Some have claimed that the bladder contraction is also voluntary.

INDEX.

PHYSIOLOGY,

EXHAUSTIVE AND PRACTICAL.

PART II.

CHAPTER VII. THE METABOLISM OF THE BODY.

SECTION I. Introductory.

The idea of Metabolism naturally follows the discussion of alimentation, secretion and excretion. It literally means "Exchange of material." We have found the changes taking place in the alimentary canal and the entrance by absorption of the elements into the blood either directly or through the lymphatic system. The waste matters are eliminated from the body as urea, CO_2, water and salts. There is an intimate relation between the food substances and these waste substances and to trace out the change from the one form to the other represents the metabolic changes in the body. Following this will be the discussion of the way in which energy liberated by these changes is distributed and utilized. Metabolism includes all that is known of the changes in the body whether these are changes of food substance or of body substance. We have already discussed under the head of alimentation those changes taking place of a digestive nature and these changes must be taken for granted as necessary in the metabolic processes. All the changes taking place in connection with the food and the body tissues are really included under metabolism but for convenience metabolism is limited to the processes involved after the food elements have become absorbed.

The two great tissues of the body are muscle and nerve, the other tissues being subservient to these. In the same way the alimentary and the excretory actions are the principal actions involved in nutrition, but other parts of the body are also engaged in changing and assimilating the absorbed food elements and also in changing the waste substances thrown off from the actively working tissues. The changes are intermediate between the digestive and excretory actions proper and are so imperfectly understood that but a vague idea can be given of the real nature of the changes. Hence most of the changes are spoken of as taking place in or in connection with the blood. The circulation of the blood through muscle and nerve and the changes through which it passes in circulating through some of the main organs of the body, such as the liver and the spleen, in the formation of such substances as glycogen, urea, etc. Certain interchanges are constantly taking place between the blood and tissues. The capillary system brings the blood into close and direct relation with the body tissues so that these tissues are constantly supplied with the nutrient elements from the blood. In tissues that are active and in the delicate tissues of the brain the capillary arrangement is so minute that each small portion is abundantly supplied with a fresh and freely flowing blood. In the cartilages of the body on the other hand where the vital processes are slow the capillary system is less rich and minute, the nourishment taking place largely, by the oozing of the fluid through the spaces between the fibres. In all human tissues therefore

there is a constant process of supplying nutriment, the matters being absorbed from the blood, these matters being transformed into the same substance as the tissues themselves or by a process of division they may be divided into simpler elements. During the activity of a muscle certain chemical changes produce disintegration of the more complex molecules of the protoplasm into simpler chemical compounds. Following this new substances are absorbed from the blood and changed into muscle protoplasm.

We have seen that the food-substances in the form of peptones, sugar and fats with various salts pass into the blood and later we found that various substances, urea, CO_2 and salts are ejected from the blood by the excretory system. It is evident that somewhere in the body active chemical processes are going on as a result of which elements that enter into the body in certain combinations are expelled from it in much simpler combinations, intermediate changes taking place which are called the metabolic phenomena of the body. For example; in muscular activity, certain chemical changes take place resulting in the change of the protoplasmic substance, producing certain simple chemical substances.

This condition implies exhaustion to be compensated for by fresh supplies furnished to the tissues from the blood. These changes are of a very delicate character and while they are largely processes of oxidation and fermentation, they are as yet very indistinctly understood. Claude Bernard speaks of the blood as the internal medium of all the nutritive changes. The blood is perpetually changing, giving and receiving new substances from the tissues, involving all the organs of alimentation, secretion and excretion, as well as the tissues themselves. In passing through the tissues the blood carries oxygen and other nutrient matters which are given up to the tissues for repair.

Each tissue receives what is best for its nutriment in this way. This selection of appropriate substances by each tissue is called the selective affinity of the tissues. These changes take place according to the physical laws that regulate diffusion and the movements of fluids through tissues or membranes, depending upon the circulation of the blood and the blood pressure. The nutrient substances of the blood pass out from the capillaries bathing the various tissues, the corpuscles of which select the materials they require,taking them up and converting them into their own substance. This is assimilation or nutrition. In some cases the corpuscles directly or indirectly from materials other than their own substance, these materials being of use in various ways to the other corpuscles of the body. This is an important element in the phenomena of secretion. The formation of ptyalin, pepsin, fat, glycogen are examples. Oxygen, as well as nutrient matters, pass out into the tissues from the capillaries and combining with some materials from the tissue elements produce chemical changes which lead to the liberation of energy in the various forms of heat, animal movements, etc. and to the formation of waste matters. In the metabolic phenomena which take place in the animal body therefore there is constantly going on a process of upbuilding or anabolism according to which changes take place resulting in the transformation of dead matter into the elements of the living organism, similar to the organic protoplasm. At the same time there is a constant process of breaking down or katabolism according to which the transformation takes place from complex chemical combinations to simpler elementary substances. In addition to this the tissues send out to the blood certain

waste matters and CO_2, the blood that returns from an active tissue being excessively laden with these waste matters, the lymph also being used as a channel for the conveyance of these substances. Thus the tissues are constantly giving and receiving materials.

ANABOLISM.—The albuminous elements of the body are built up entirely from the albuminate proximate principles of the food. The albuminous elements of food are converted during the digestive processes into peptones and these peptones become albumin in the blood. The fat of the body is formed partly from the fatty substances which enter the body in the form of food and partly from the proteid constituents of the food. Hence, fat may be formed in the body although all fatty substances are excluded from the food. Liebig thought that the carbohydrates were converted into fat, but this is only true to the extent that the carbohydrates aid in the dissociation of the albuminates to form fat. The carbohydrates play an important part in the formation of fat, possibly combining with oxygen, they prevent the oxidation of fat or of substances producing fat which therefore accumulate in the body. A large proportion of the fat is formed from the albumin. It is found that when the albuminous tissues of the dead body are placed under the action of water adipocere is formed. In the case of feeding upon flesh diet the nitrogen passes off in the waste while the carbon is held in the system to aid in fat formation. The albumin seem to be dissociated into the nitrogenous and non-nitrogenous elements, the latter assisting in fat formation. Thus the fat is derived from the fat taken directly in the food and from the transformed albumin of the food. Hence anything that prevents albuminous substances from being decomposed or that prevents oxidation processes assists in the fat formation. If this fat in the body passes beyond the normal obesity results. In order to prevent this it is necessary to prevent the use of fatty food, only albuminous substances being used in the form of food so as to permit of the oxygen freely acting on the non-nitrogenous albumin products and preventing fat formation; and the muscles require to be exercised freely so as to oxidize freely the foods.

KATABOLISM.—Katabolic changes are carried on by the free presence of oxygen. The breaking down of the nitrogenous matter yields by a series of steps nitrogenous waste in the form of kreatin, uric acid, urea. But from the carbon and hydrogen of the nitrogenous matters there are formed by the combination with oxygen non-nitrogenous waste products, water and CO_2. The oxidation of the non-nitrogenous or of carbonaceous materials of the body yield these non-nitrogenous waste products. Hence while the notrogenous waste products which are eliminated from the body can be derived only from the albuminous food elements the non-nitrogenous matters are produced by chemical changes taking place in connection with the carbonaceous and nitrogenous elements of the food. The first step in the process is the setting free of oxygen from oxyhaemoglobin. When liberated the oxygen combines with certain of the elements found in the tissues resulting in the production of a number of chemical compounds. Resulting from this combination we find the liberation of energy in the form of animal heat and certain mechanical movements of the body to be deferred until later.

Thus the metabolic processes are two-fold and of an opposite character. The living protoplasm undergoing changes in connection with the food upbuilding and the complex substances being broken down into simpler substances. The former form new molecules and the latter break

up and are excreted as disintegrated molecules. These two processes involve the increase and diminution in size. Within the same cell or combination of cells these two processes may be going on simultaneously so that the two processes may balance each other or represent an excess on one side, representing either a condition of equilibrium or on the other hand growth or degeneration. The metabolism may be determined by the nature and the amount of food supply and by the environing circumstances such as temperature. In addition to this the metabolism may be definitely determined by nervous connection, certain nerve fibres according to Gaskell having a trophic influence and therefore furnishing impulses that determine the changes whether katabolic or anabolic. The vagi and sympathetics in connection with the heart are said to have respectively anabolic and katabolic influence, diminishing and increasing respectively the activity of the organic substance. Hering holds that where the katabolic or anabolic changes take place there is a tendency to produce a reaction towards the other metabolic process, in this way tending to develop metabolic equilibrium between anabolism and katabolism. This accounts, according to Hering, for the power of self-regulation internally manifested in the adjustment of the metabolic processes so that when any one of the processes takes place in any portion of the protoplasm the opposite process is originated in the adjoining part. It must be remembered that changes take place outside of the actual particles of the body substance involving both the constructive and destructive processes under the influence of oxidation, such changes being distinctly marked off from those taking place in the actual protoplasmic substance.

SECTION II. Nutritive Balance and Value of Food Stuffs.

In order to estimate the body metabolism and its value we must estimate the nutritive value of the food stuffs used in dieting. This can be done by estimating the ingesta and excreta. By estimating the entire nitrogenous excreta we can estimate the proteid matter used up in the body nutrition. The form of estimating will be discussed under nutrition proper. Out of the proteid and albuminoid materials under the process of oxidation the nitrogenous materials are found as urea, uric acid, kreatin and xanthin excreted in connection with the urine. The main nitrogenous excrement of the urine is urea, but it is more satisfactory to estimate the entire nitrogen in the urine for a definite period reckoning the amount of proteid necessary for the production of it. In this way all the nitrogenous excreta are taken account of. Proteids do not differ much in the quantities of nitrogen which they contain which is estimated at 16 per cent and as this represents 6.25 as the proteid ratio, all that is necessary is to multiply the amount of nitrogen by 6.25 in order to find the amount of proteids con-sumed.

To determine this total quantity of nitrogen it must be estimated in faeces and urine, because all the ordinary proteid does not pass through the digestive process, the amount found in the faeces requiring therefore to be deducted from the amount taken in the form of food in order to find the amount used; and also as the secretory process uses up a quantity of nitrogen the total amount of nitrogen used cannot be estimated simply from the urine excretion. There is a small nitrogenous excretion in connection with the perspiration, the salivary secretion and the

mammary secretion, but these are so small as to be almost inappreciable. In order to estimate the non-nitrogenous materials used up in the body metabolism it is necessary to know the amount of nitrogen found in the body excretions and the amount of carbon found in the body excretions including the lungs. An estimate can be formed from the entire nitrogen of the amount of proteid consumed, translating this into a corresponding quantity of carbon and deducting it from the total amount of carbon used, to get the amount of carbon arising in connection with the metabolism of the non-nitrogenous fats and carbohydrates. In this way we can estimate the amount of proteid, carbohydrate and fat used in the metabolic processes. By comparing this with the quantities of the same substances used as food during a certain period it is possible to determine how much of the different substances has been used up in the body metabolism, and how much has been used in storing up fat, etc., in the body; and also we can determine whether there is a larger consumption in the metabolism than the food supply furnishes. This is what is meant by nutritive balance. These experiments require much time and laborious work. Such work has been done by Voit and Pettenkofer who have experimented upon man in determining the amount of nitrogen from the urine and faeces and also the amount of CO^2 excreted in connection with respiration. In this way the nutritive value of the food stuffs has been almost accurately estimated as well as the nutritive action of these food stuffs in the metabolic processes.

Two terms are frequently used to represent the result of some of these experiments. Nitrogen-equilibrium represents a condition in which during a definite time the nitrogen of the ingesta and excreta are equal, that is, the loss of proteid in the body is exactly covered by the gain of proteid in the food. If more nitrogen is excreted than is found in the food then there must be a loss of body proteid to furnish the nitrogen; if on the other hand less nitrogen is excreted than is found in the food supply proteid must de added to the body. In the normal condition of a healthy adult there is this nitrogen-equilibrium. In the case of the growing and immature individual there is a proteid storage taking place which interferes with the preservation of equilibrium. Of course the standard of equilibrium will depend upon the digestive and absorbent power of the stomach and internal organs. Carbon-equilibrium represents a condition in which during a definite time the entire carbon of the ingesta and excreta are equal. There might be a loss or gain of weight with nitrogen-equilibrium because in addition to proteids there are non-proteid substances, such as sugar and fats provided in the food and used up in the metabolism of the body. The same thing will be true of equilibrium in the other proximate principles of the food, such as water, salts, etc. The general variation is found in the carbon-equilibrium as the loss or gain of the body is usually found to be connected with body fats which depend upon the carbon provided and used up by the body.

PROTEID METABOLISM.—The serum-albumin and serum-globulin which represent the proteit of the blood are replenished by proteids absorbed from the alimentary canal and changed in passing through the epithelium. The peptone form of the digested proteid is changed after or during absorption. It seems necessary that the blood should not contain peptone, at least in the albumose form, as it seems to affect the blood when added to it so as to render it unfit for its circulatory purposes. Proteids are taken into the blood as albumin, casein, myosin, and the globu-

lin of cereals. In nutritive value the proteids are almost equal, less of vegetable proteid being assimilated than of animal proteid. The peptones represent about the same value as the proteids from which they originate. Serum-albumin and serum-globulin have the same nutritive value if injected into the blood, egg-albumen and peptone not being assimilated if injected but passing off in the urine. Hence the peptones are changed either directly or indirectly into the blood plasma proteids. A small part is decomposed into the amido-compound form in the intestines under the action of tripsin or by putrefactive changes. This proteid matter carried by the lymph comes in contact with the tissues becoming oxidized in connection with the tissues and broken up into the simple CO_2, H_2O and urea forms. This breaking up of the proteid takes place under the action of the living cells resulting in the liberation of energy. Under this oxidation process part of the proteid is destroyed without being assimilated to the cell substance. This is called by Voit "the circulating proteid," which is found in every animal in connection with the lymph and tissues. This accounts for the fact that in the case of an animal deprived of food for the first few days after the deprivation of food more proteid is used up in the metabolism until the floating proteid is exhausted when the amount of metabolized is diminished. In addition to this floating proteid there is a portion of proteid which goes to build up the tissues by way of repairing the nitrogenous waste or for the purpose of forming new tissue. This Voit calls the tissue proteid. This does not mean that the proteid when absorbed is of two kinds but simply refers to the two-fold disposition of the proteid after it has been brought to the tissues by the blood, one portion becoming part of the already existing tissue and another floating in the blood and tissues. Proteid is necessary for the repair and formation of tissue as the absence of proteid in feeding upon non-nitrogenous food such as fats and carbohydrates alone finally results in death. Nitrogen is necessary to tissue protoplasm, and the nitrogen must be in proteid form as the nitrogen-equilibrium can not be upheld in dieting on such nitrogenous elements as the amido-acids or gelatin. In this latter case the excretions will gradually lose their nitrogenous elements, these being consumed within the body until death ensues. Thus there exists an absolute necessity in body metabolism for proteid in order to the formation and repair of the body tissues. In addition to this, proteid is also used in the process of oxidation so as to produce heat, energy etc., this proteid forming the source of energy for the body. Thus there are two uses for proteid matter in diet, viz. tissue upbuilding and energy production. In proof of this it has been demonstrated that a carnivorous animal upon a flesh diet can be kept in a condition of carbon and nitrogen equilibrium. Pfluger, Pettenkofer and Voit have experimented on dogs keeping them on a flesh diet and preserving the body equilibrium, indicating that proteid substance alone is sufficient to furnish all that is necessary for body metabolism and also for the production of body energy. It is on account of the economy of fat and carbohydrate dieting that these are resorted to as such substitutes. According to this the tissue proteid goes to tissue repair and development, the overplus representing the floating proteid being utilized in the production of heat and energy, the excess above use and necessary supply being destroyed and excreted from the body. Animals as well as human subjects possess a large capacity for the consumption of proteid, very rapidly destroying any excess over what is necessary for use.

In the oxidation of proteid for the purposes of producing energy, fats and carbohydrates may be substituted, at least in part. It is not sufficient to provide proteid simply for tissue repair. In the case of an animal deprived of food, after several days the amount of nitrogenous waste reaches a minimum after which it remains constant. If at this stage sufficient proteid is given to supply the waste there is still a loss of body proteid and in order to maintain the body equilibrium more proteid must be given. If fats and carbohydrates are given along with the proteid, less of the proteid is necessary to establish equilibrium. As we saw before, the proteid becomes tissue proteid and floating proteid, a part of the latter being destroyed so that more proteid must be furnished than if the entire proteid became tissue building. If fats and carbohydrates are given as food there is less proteid destroyed and hence a larger proportion of the proteid goes to the building up of the tissues. In the case of the use of the albuminoid substance gelatin as food along with the proteid or along with proteid, fat and carbohydrates a smaller proportion of proteid is sufficient to maintain body equilibrium, the albuminoids in this case taking the place of the floating proteids. The excess of proteid above what is necessary to maintain equilibrium has been spoken of by some physiologists as luxus and that this involves the destruction of an unnecessary amount of food matter in the metabolic process. It has been shown, however, that an excess of proteid is really necessary in order to maintain the functional activity of the metabolic and excretory systems. Of course, if the excess is too great the activity of the metabolism will be increased unneccessarily and this may result in gastric and intestinal disorders.

In regard to the albuminoids the chief of which is gelatin derived from bones and connective tissues it is very like ordinary proteid but it does not maintain the nitrogen equilibrium. It is like proteid and forms the gelatin peptone but differs from the proteids in chemical composition and can not take the place of proteid in chemical composition and can not take the place of proteid in metabolism. It can not form new tissues. One of its chief functions is to spare the proteid acting very much like, although more efficiently than the carbohydrates. It is found usually in soups and other boiled meats. If an animal were fed upon albuminoids alone or even with fats and carbohydrates, the tissue will yield to disintegration producing excessive nitrogen in excretion resulting in a condition of emaciation and death. In connection with the digestion of gelatin, gelatin-peptones and gelatoses are formed, these being absorbed and under oxidation forming CO_2, H_2O and urea, resulting in the production of body energy. The use of albuminoids renders unnecessary the same amount of proteid, the albuminoids taking the place of the floating proteid and being subjected to oxidation, leaving the proteid to form the tissue proteid. This gives to the albuminoid a special nutritive value next to the proteid itself, as the albumenoid can take the place of that portion of the proteid which is destroyed and acts as a protector and economizer of proteids in the metabolic process. Nucleins and nucleo-proteids are found in connection with the normal dieting. Nuclein, at least, in part becomes absorbed and changed to other substances producing an increase of uric acid in the urine and furnishing iron for haemoglobin as well as phosphorus which becomes phosphoric acid and is excreted as phosphates. In the case of the amido-acids they have the function of sparing the proteid so that where vegetable food is used we find these amido-acids as

proteid accessories.

METABOLISM OF FATS.—As we saw the absorption of fats takes place in connection with the lacteals being finally carried to the blood in the condition of neutral fats. After this they are subjected to oxidation resulting in the production of CO_2 and H_2O and of a certain amount of energy. The fats thus furnish body energy. The adipose tissue of the body contains fat which is used as a reserve stock in the absence of the supply of the necessary material in the food. When there is an excessive supply of fat taken in the food what is in excess of use is stored up in connection with the adipose tissue. Fatty acids and soaps possess almost the same value in nutrition as fats from which they are derived. Glycerine acts in certain cases as a sparer of fats also sparing the conversion of glycogen to sugar. In the case of an animal deprived of food there is first drawn upon the glycogen and later the body proteids and fats, the fat supply, if large, protecting theproteids from excessive drain. Hence, the animal with little or no fat in the form of adipose tissue will not survive long under starvation. Fat was at one time said to be derived primarily from the fat taken as food. But this is not the only source, nor is it the real source of fat, as it has been proved that fat formed in the body is largely in excess of the fat taken in the food In addition to this the fat in different animals differs in its nature, depending somewhat upon the variety of the animal's food. This difference can be analyzed microscopically. Some physiologists claim that none of the fat stored in the body is taken directly from the fat of the food, the fat taken in the food being completely oxidized and the body fat arising from changes taking place in the proteids and carbohydrates. According to Voit the proteids mainly yield body fat. In metabolism the proteid is broken up into nitrogenous and non-nitrogenous elements. The nitrogenous element is changed into urea while the non-nitrogenous is converted into fat and glycogen. By feeding dogs on lean meat (proteid) it was found by Voit that less carbon was excreted than was taken in the food, this carbon being kept in the body as fat. It would seem that the proteids do yield fat but not all or nearly all the fat of the body as Voit thought. Liebig on the other hand states that the fat of the body originates largely from carbohydrates. This was disputed by Voit but more recent experiments indicate that the carbohydrates form the principal source of body fat. This is confirmed by the fact that in the process of stock feeding the best food is that largely carbohydrate with some proteid, the fat being formed directly from the carbohydrates.

METABOLISM OF CARBOHYDRATES.—The carbohydrates are taken largely from vegetables, except glycogen and sugar found in meat and lactose in milk. The chief of these are starch, cane and grape sugar. Large quantities of starch can be taken as food and absorbed in the blood without producing glycosuria if the animal is in normal condition, but if the digestive powers are impaired glycosuria readily results. If large quantities of cane sugar or maltose are taken portions of the sugar will appear in the urine because the sugar can not be taken with sufficient rapidity to the liver by the blood so that part of it gets into the general circulation and to the kidneys.

The carbohydrates like the fats become oxidized and supply body energy in addition to the conversion into fat which is stored up in the body. In ordinary dieting, carbohydrates form the larger part of the food being readily digested and oxidized and also an economical diet

In the oxidation of the carbohydrates CO_2 and H_2O are produced, less oxygen being necessary for this oxidation than that of the fats or proteids. In the case of sugar only so much oxygen is necessary as will produce oxidation of the carbon producing CO_2. The carbohydrates are absorbed chiefly in the blood sugar form of dextrose, the excess being changed to glycogen and stored in the liver for later use in transformation to dextrose. In the tissues the sugar particles are supposed to be first of all broken up, lactic acid being formed and oxidation taking place. Others suppose that in the dissolution of sugar particle CO_2 and alcohol are formed as in the fermentation process. Others combine the oxidation and fermentation process in connection with the carbohydrate dissolution. Mering has shown that by excising the pancreas in the case of a dog the power of using sugar is lost to the tissues the sugar accumulating in the blood and passing to the urine producing diabetes. This does not take place if the pancreas is partially removed only, indicating the formation in connection with the pancreas of a secretion which passes to the blood of value in connection with the using up of sugar. In some way, therefore, the pancreas is associated with sugar consumption and this has an important bearing on the cause of diabetes in which the tissues are unable to oxidize the sugar so as to prevent it from escaping unoxidized in the urine. The solution of this according to some is that there is an enzyme which passes to the blood in connection with pancreatic action, the enzyme being capable of dissolving the sugar. In proof of this it is claimed that sugar when added to blood is very rapidly dissolved in the blood. Lepine and Barral have called ths process glycolysis and they call the enzyme glycolytic. It has not been clearly demonstrated that this ferment exists in the circulating blood although it certainly does exist in the blood when shed.

Metabolism of Water and Salts.—Water is excreted in connection with the skin, the lungs, the urine and the faeces. Water is introduced in connection with the food and partly formed within the body in the lungs and in connection with the oxidation and secretory processes. Water is absolutely necessary in the tissues and in connection with the other fluid secretions of the body in order to body metabolism. Where the loss of water is produced by exercise or other normal conditions the nervous system provides for the supply of more water in the production of the thirsting condition. Water does not produce energy, as it is excreted in the form in which it is taken. It takes the place of water lost and provides the medium in which the chemical changes take place.

Inorganic salts, chiefly chlorides of sodium and phosphates of lime, are essential to the body metabolism. These salts like water do not directly furnish any body energy, most of them being eliminated from the body in the same form in which they are taken. In connection with the metabolism, however, sulphates and phosphates are formed and changes take place in the dissolution of the chlorides to form the hydrochloric acid of the gastric juice. The chief value of the salts lies in the fact that they are essential to the maintainance of the normal condition of the tissues and the fluids of the body. It has been found that to reduce the salts without changing the other dietary elements produces quickly fatal results, the deprivation of salt having more serious results than the deprivation of food. The fatal results in this case arises from chronic acid poisoning, according to Bunge, resulting from the oxidation of sulphur from the porteids. This acid is usually neutralized by the salts taken

in the food. In addition to the salts it is necessary that they be in proper combination with organic substances. The proteids are always naturally combined with inorganic salts which in part at least give to the porteids their characteristic qualities. Originally in the vegtable kingdom there is a corelation of the organic and inorganic elements and in dieting of animals it is necessary to preserve this connection in order to preserve the value of the organic substances. Bunge points out that carnivorous animals do not desire so much salt as herbivorous animals accounting for this by the fact that in vegetable food there is an excess of potasium salts; these salts when taken into the body reacting with sodium chloride resulting in a dissolution, forming pottassium chloride and the sodium of the salt formerly in combination with the potassium, the new salts being excreted from the kidneys. This produces a decrease of sodium chloride and consequently a desire for common salt. In line with this it is found that vegetarians use more salt than those who use animal food. The same thing is true of those who live almost entirely on fish or on food composed of vegetables not having the potassium salts in great abundance. Those who do not live upon vegetables and carnivorous animals have no such desire for salt. The iron salts are necessary in connection with the formation of new red blood corpuscles, in connection with haemglobin to supply the loss of iron in connection with the breaking up of the red corpuscles. The amount of iron excreted is very small, so that the amount necessary in the food is also small. The small excreta of iron does not represent the iron subject to metabolism because the iron of the disintegrated red corpuscles is kept in the blood and used again in the integration of corpuscles. Iron is found in animal and vegetable foods in the organic compound form and in this form it is freely absorbed and used in the metabolic process and finally excreted from the body in the faeces. Bunge calls the iron compounds found in nuclein, as in egg neclein, haematogen. In cell nuclei and the haemoglobin of flesh, iron is taken in the food being in combination with the organic substance. Calcium salts are essential in the food especially in the growing and development of the bones and in the general tissue development, as well as formoing a necessary element in connection with the blood in its property of coagulating, muscle, especially heart muscle, in its contractility and protoplasm in general. The amount of calcium salts absorbed is small and its excretion takes place through the faeces. It is taken in in organic compounds possibly with the porteids. Milk and the yolk of eggs contain large quantities. Leguminous plants also contain quantities of lime. In regard to the accessories of diet, including alcohol there is considerable division of opinion. These include articles taken along with the food to stimulate the appetite or assist digestion. There is a small nutritive value in these but so small that we may say there is really none, as they may be omitted from food with hardly any disadvantage except so far as lack of flavor is concerned. Some regard alcohol when taken in small quantities as of nutritive value as a non-proteid in lessening porteid oxidation by becoming itself oxidized. When thus oxidized it furnishes energy. It is doubtful if such is the case as a small proportion when taken scarcely if ever reaches the metabolic stage a part of it being exhaled in expiration. The evidence is much divided. Rechert has found that small doses of alcohol administered to dogs does not affect the body heat. In this case the alcohol would act as a portector of porteid and non-proteids, rendering their oxidation unnecessary.

Miura experimented upon himself substituting alcohol for carbohydrates, the result being a loss of proteid, indicating that the proteid was not protected by the alcohol, but rather that it increased the proteid consumption. If taken in large quantities its effect will be the opposite, producing an increased waste of proteid. Its effect upon the tissue substance is injurious especially in its effect upon the nervous system which is so exhausting, that the evil effects more than counterbalance any good effect it may have in connection with proteid oxidation.

SECTION III. Metabolism in Connection with the Deprivation of Food.

Metabolism being concerned with the changes taking place after the food elements are absorbed, before and after reaching the tissues, the simplest metabolic condition is found in the case where an animal is deprived of food either partially or altogteher, because here the body element is utilized in the metabolic processes. It is of importance to consider the processes so far as these can be followed in connection with the excretions in such starving conditions. Even when food is withheld the excretions do not cease, although there is a change in these excretions. In the case of the faeces we find that an almost normal amount is passed although not with the same regularity as in cases of regular dieting. While life lasts there is an excretion of urea and CO_2, the nitrogen loss being sustained upon the lowest level because life is sustained at the lowest mark. A starving animal lives upon the nutrient matters present in the body, including fat stored in the body, glycogen and circulating tissue proteid. The faeces are found to consist of a viscid semi-liquid secretion and thickened digestive juices together with broken down epithelium cells and general waste in the body tissues. The urine is also continued with little variation from normal. The skin excretes its fluid secretion and the lungs also excrete CO_2 and H_2O. From all these excretions there is a drain on the body system which gradually diminishes the body size and weight. It is during the first two or three days that the proteid loss is greatest on account of the fact that the products of the proteid metabolism found in floating proteid form and still found in food form in the alimentary canal are exhausted. This floating proteid is very soon exhausted depending upon the amount of muscular exertion. It is after the first two days that the real period of starvation begins. After this the average loss is steady from day to day, gradually being reduced to a minimum, this being due to the fact that the animal lives upon its own fat and proteid, namely the tissue proteid. Voit found in the case of a cat deprived of food a daily excretion in the form of urea representing about thirty grams of proteid tissue, the loss being about regular for ten or twelve days after which the amount increased. The period when the nitrogenous loss begins depends upon the condition of the animal and the nature of the previous dieting. According to the experiments of Voit made upon dogs the loss started at once where the diet before the deprival of food was comparatively small in amount with but little proteid food, from the third to the fifth day in cases where the animal has been regularly fed with a normal proportion of proteid food. The amount of the excretion is found to vary with different animals, smaller animals using up in metabolism a larger amount of proteid per unit of body weight because the body surface is larger in proportion in these animals. The same is true of lean as com-

pared with fat animals. Results in the case of fasting amonng human subjects differ from animals. There is a continuous diminution of nitrogen excretion with a decrease in the chlorines and alkalies in the urine for several days. Some of the C in the case of proteid destruction is stored up as glycogen. Cetti applied the same experiments as Voit to man. He found in the case of a man weighing 125½ pounds the daily urea excretion during the first ten days of deprivation of food about twenty grams, representing eleven grams of N. In the cases in which there is a large quantity of body fat the N excretion is found to be less. In the case Succi whose weight was 138½ lbs. at the beginning of his fast, on the tenth day of his fast he excreted 6.7 grams of N, on the twentieth day 4.3 grams of N and on the thirtieth day 3.2 grams of N, his body weight being reduced by the thirty days fast to 114½ lbs. a loss of twenty four pounds. Observations by others have made the loss vary from 5.29 grams to 13.7 grams of N daily which would represent the amount that would be required as a minimum in food in order to preserve nitrogen equilibrium. It is noticed in herbivora that instead of a decrease of nitrogenous excretion there is an increase, the animals in this case feeding upon their own body tissue. The ordinary estimate is formed from the amount of urea in the ~~of the~~ destruction of proteid taking place in the body when the animal is deprived of food. This destruction of proteid goes on even where there is sufficient fat in the body to supply non-nitrogenous material. After the starvation process has gone on for some time there is often an increase in this proteid destruction, chiefly because the other non-proteid matters have been exhausted in the oxidation processes so that all the available matter is the body tissue which is essentially proteid tissue.

During the period of deprivation of food CO_2 is excreted from the lungs bearing a direct ratio to the body weight and the energy expended and in inverse ratio to the surrounding temperature. Voit found in the case of a man weighing 156½ lbs. during the first day after being deprived of food 201 grams of C excreted by respiration, in the urine 5.8 of C and 12½ grams of N. This was equivalent to almost 79 grams of proteid and 215 of fat. At another time when fasting the same individual while working on the first day of his fast lost 75 grams of proteid and 380 grams of fat. Oxygen was taken in the former case to the extent of 760 grams and in the latter 1,072 grams and there were 889 and 1,777 grams of water excreted. During fasting the body temperature remains normal for a time as the fat and proteid oxidation goes on. After a time however the temperature falls at first gradually and later very quickly, all the tissue nourishment being practically used up in oxidation so that very little material is left for keeping up the oxidation and hence preserving the temperature. Of course the fall in temperature is partly due to the degeneration of the nervous system on account of lack of nutrition. It is claimed by some that the application of artificial means of warming a starving animal will prolong life in the last stages of death from starvation as this reduces the amount of oxidation necessary to preserve warmth, thus saving the oxidizable substances in the body. This prolongation of of life, however, will be but short because warmth alone can not sustain life. During the starvation of an animal the different organs of the body suffer loss in different degrees, the heart and nervous system maintaining longest the normal condition and remaining almost unimpaired because they live at the expense of the rest of the body. The first parts to

be used up are those parts of the body which are least necessary to the body, the adipose tissue being the first to yield so that when death takes place not more than ten per-cent of the body fat has survived the process of starvation. Next to the fat is the glycogen stored up in the muscles and liver, the muscle glycogen being preserved longest. The first organ to manifest diminution in size is the spleen, next the organs associated with digestion especially the glands connected with the secretion. Then the muscle begins to yield giving rise to emaciation, the emaciation being considerable if starvation is prolonged and body weakness. After the blood has been nourished upon these other organs it begins to consume its own substance at the same time drawing the nutriment from the lungs, kidneys, pancreas and the bones. At this point naturally the heart and nervous system would fall a prey to blood nourishment but they seem to resist the call for disintegration, the result being death, the weight having gone down from 25 to 50 per-cent. In the case of a cat starved under the inspection of Voit only three per-cent of the heart and three per-cent of the nervous system were found to be lost, although this percentage has been found to be larger by other experimenters. Voit took two cats of about equal weight and after feeding them for ten days killed one and starved the other for thirteen days. During the thirteen days the cat lost 1,017 grams in weight, the largest loss being in the muscles over 425 grams, the fat losing the largest percentage as it had practically disappeared from the body. The heart and the central nervous system lost scarcely any weight at all because they fed on the rest of the body.

In the complete deprivation of food the nitrogenous excretion arises from the tissue nitrogenous metabolism. It might be supposed that by giving in the form of food to such a starving animal an amount of nitrogenous food in proteid form exactly equivalent to the amount of loss, the tissue waste would be arrested the loss being thrown upon the non-proteid substances. That this is not true is proved by experiments in which more nitrogen is lost than is given in form of food. All the nitrogen of the proteid food appears as urea in the urine and there is an added amount of nitrogen arising from the tissue proteid. Voit by a number of experiments concluded that in order to maintain nitrogen equilibrium in a starving animal it was necessary to give to the animal an amount of proteid equal to 2½ times the proteid that is subjected to metabolism during the deprivation of food. This is necessary because after or during starvation the exhaustion of tissue proteid is so complete that to give proteid food causes digestion of an increased character; producing an increased metabolism and therefore an increased demand for materials for the oxidation process. This is an important question but one that as yet is not distinctly understood. In the case of giving as food to a starving animal non-proteid substances the same stimulation does not take place in connection with metabolic processes.

The albuminoids, fats and carbohydrates act as economizers and protectors of the tissue proteid rather than exciting to increased activity, having the opposite effect, that of diminishing the amount of tissue proteid oxidized. Voit found that nitrogen-equilibrium could be preserved with a much smaller amount of proteid if a definite quantity of fat or carbohydrate was given along with it. If in the case of an animal deprived of food there is given an amount of proteid in excess of the nitrogen loss represented in the excretions very soon the drain upon the tissue proteid of the body ceases and the proteid tissue begins to build up again.

This results in an increase of body weight, this increase continuing until a certain limit is reached when the nitrogen-equilibrium is again restored, the increase of proteid resulting in an increase of body tissue. By increasing this amount of proteid food the digestive power will be increased until a point is reached which according to Voit represents a metabolism fifteen times greater than that of the starving condition. According to Voit, in the case of dogs, nitrogen equilibrium can be preserved with as small a quantity as 500 and as great a quantity as 2,500 grams of proteid. When the amount is increased beyond this limit digestion is impaired. A man in ordinary civilized conditions requires less in proportion on account of hygienic considerations. If on the other hand the amount of proteid food is diminished gradually, the nitrogen equilibrium may be established on a smaller quantity of proteid, there being a loss of body weight until this N equilibrium is reached, after which the body equilibrium may be maintained if the proteid metabolized is constant. This indicates that there are different levels at which N equilibrium may be sustained. The amount necessary to sustain N equilibrium depends upon the condition of the organism, a well fed body requires more than a badly fed or emaciated body. According to Voit the smallest quantity sufficient to sustain N equilibrium in a dog is 480 grams of lean meat, proteid, or 16 grams of N, 35 grams of urea or equal to three times the average daily loss of N during starvation. It is estimated that on a normal basis of dieting about 85 per cent of the proteid taken as food is oxidized and excreted, the balance being added to the tissues of the body.

Much discussion has arisen as to the minimum quantity of proteid that is required to preserve in health and in fit condition for ordinary work an individual, in other words, the dividing line between partial starvation and normal dieting. Ranke has made a normal diet for a man of 154 lbs. to consist of 100 grams of proteid, 100 grams of fat and 240 grams of carbohydrates daily. In this case the individual was not supposed to do any muscular work. Voit estimated the amount for the same individual doing muscular work at 120 grams of proteid, 56 grams of fat and 500 grams of carbohydrate, representing 19 grams of N and 330 grams of C. According to more recent investigators about 100 to 105 grams of proteid in the case of a man of the above weight is subjected to the metabolic process. It must be borne in mind that if the non-proteids are increased the proteids may be decreased without interfering with the nutrition proper.

Hirschfield sustained himself on from fifty to 75 grams of proteid daily by increasing very much the amount of carbohydrates taken along with it. Others have reduced the amount to 25 grams, requiring however 270 grams of fat and 400 grams of carbohydrate in order to keep up the N equilibrium. Munk experimented upon a dog feeding it for a time on pure proteid. He then cut off half of the proteid, replacing it by non-proteid, continuing to decrease the proteid and increase the non-proteid until digestion of the non-proteid became difficult, the amount of non-proteid used in such a case being very large. The carbohydrates are found to be better adapted for proteid saving and protection than fats, the albuminoids being better even than the carbohydrates. According to Voit the amount of proteid loss in the body can be reduced to half of that lost normally, if sufficient quantities of gelatin are given in the food. Munk estimates that five-sixths of the necessary N can be derived from gelatin. It must be remembered that dieting on fats, carbohydrates or

gelatin diminishes the nitrogeneous excretion and also the amount of phosphoric acid. Schaefer concludes that to reduce to less than 100 grams of proteid the normal diet would interfere with the maintenance of equilibrium in the human subject. Hultgren and Lantergren have collected statistics among Russian, German and Swedish workingmen among whom he finds the proteid used varying in the ordinary diet from 130 to 190 grams daily, so that they give the ratio of proteid to non-proteid food constituents as 1:4.25 in weight and of fats to carbohydrates 1:6.35.

SECTION IV. Metabolism of Body Substance.

The animal food as we have seen consists of water, inorganic salts, together with the organic nitrogenous and non-nitrogenous elements. In the case of the vegetables they live upon inorganic substances, part of which is nitrogenous, out of which the vegetable life constructs organic substances, including proteids, fats and carbohydrates. This food organized in plant life becomes the basis of animal food. It was at first supposed by Liebig and others that there existed an essential difference between the organization of the vegetables and animals, the vegetable having the power of combining while the animal did not possess this power but must find the materials already combined directly or indirectly from the vegetables, which were regarded as the synthetizers. This idea has been modified, as the synthetizing power is found in animals as well as in plants. Woehler discovered that benzoic acid used in food becomes hippuric acid when found in urine, a synthesis taking place between benzoic acid and glycin at a high temperature and under the action of pressure. This synthesis in the case of dogs has been found to take place in the kidney and can be produced artificially by the passage of blood with the benzoic acid and glycin through the kidney or even by mixing it with the kidney cut up into pieces. It has been found that if the kidney cells are destroyed there is no change to hippuric acid. Hence it is concluded that the benzoic acid furnished in the food passes into the kidney, comes into association with glycin which comes from the tissues and by the activity of the cells forms hippuric acid. By the extirpation of the kidneys the process of hippuric acid formation is stopped, although this is not the case in frogs and rabbits in which it seems to take place in the other organs. Urea is formed in the liver in the same synthetic form out of ammonium carbonate and ammonium carbamate. In the case of birds uric acid instead of urea is formed. Glycogen is also formed out of glucose in the liver and the muscles. Proteid substance is formed from peptones in connection with the mucous lining of the alimentary canal; fatty acids and glycerine unite to form fats in the intestines; carbohydrates forming fats and the non-nitrogenous elements of the proteid substance also uniting to form fats. These are all examples of the combination of simple substances or broken down materials to form the compound substances, this combination being the opposite of the process of dissociation. The synthetic processes seem to be as essential to body metabolism as the analytic processes. This contradicts the older Liebig theory of metabolism in animals as distinguished from that of plants, the former being analytic and the latter synthetic, although the form of the synthesis is as yet but vaguely understood. Liebig's theory still holds goods to this extent that the plants build up nitrogen into proteid from the inorganic substances, the animals not having this power. Physiol-

ogical chemistry is able to construct out of minute atoms the organic compounds. The question is, can the artificial means used, namely, high temperature, great pressure and the use of chemical agents be taken to represent the vital processes of the living cells. Although these forms of synthetic combination are beyond dispute it is as yet unproved that in the formation of living protoplasm any other material than proteid is capable of such synthesis in connection with the animal organism. The proteid elements must be found in the food, pass through the alimentary changes, assume the blood-proteid form and in this form become synthetized. We are unable to state how this non-living proteid can be synthetized in connection with living proteid tissue.

In connection with the katabolism of the body substances there are two important elements in the change: (1) a dividing of the complex molecules into the simpler form of molecule, and (2) the resulting molecules are subjected to oxidation, at least some of them. These two changes occur at different periods and in all likelihood, at different points in the body substance. When the complex molecules are divided up in connection with the muscle proteid, the oxidation does not take place, at least fully, as certain substances like lactic acid leave the muscle to be oxidized elsewhere. The oxidation process is probably the more important element in the change because in the formation of the products of metabolism the substances become completely oxidized. It has not been proved however that the splitting up process is of necessity associated with oxidation for the oxidation may not and does not in the case of a part at least of the split-up elements take place at once. Proteid, for example, has been found to be split up in the separation of urea, the remainder taking the form of CO_2 and H_2O, these substances being discharged at different times. Where the oxidation processes are interfered with certain oxidizable sub stances such as lactic acid are found in the blood and passed off in the urine excretions. Living proteid molecules fall to piecesand molecular atoms of unliving proteid taken as food come under the influence of the living substance and become part of it. In what way this change from the dead proteid or protoplasm to the living proteid or bioplasm takes place we cannot explain. Pfluger thinks that the nitrogen in the living proteid is found in the compound radical cyanogen form and that in the dead form it is in the compound amide form, hydrogen being replaced by the acid radicals. He accounts for the active power of the bioplasm in dissociation and combination on the basis of molecular movements among the cyanogen radical atoms. This and other similar explanations are purely theoretical. We cannot tell what constitutes the difference between protoplasm and bioplasm, nor can we tell what makes the difference between different parts of the bioplasm. One thing seems to be evident that the bioplasmic molecule has a greater tendency to fall to pieces than the protoplasm, the process of breaking up being definite, the final products when oxidized being CO_2,H_2O and other nitrogenous substances which change in the production of the last products that appear in the urine, urea, uric acid, hippuric acid, kreatinin, and ammonia.

Relative Tissue Metabolism.—The tissues of the body exhibit different degrees of metabolic activity, all the changes taking place that are at the basis of the production of heat and energy in those tissues. Older physiologists believed that oxidation processes took place in the blood to a large extent. It is true that oxidation does take place in or in connection with the blood. By allowing blood to stand in a closed vessel, even

when sealed in a tube, the oxygen separates from the oxyhaemoglobin, this being due, as some think, to certain chemical reducing substances, or more probably to the action of the leucocytes and bacteria, the latter very quickly appearing in standing blood. Aside from the oxidation taking place in the blood the large oxidation processes take place in the muscles and other tissues of the body. Experiments on frogs, whose blood has been replaced by a sodium chloride solution, have indicated that the same amount of O is taken in and the same amount of CO_2 given off. In other animals it has been found that the reduction of the volume of blood very considerably has not interfered with the oxidation processes. Leaving the blood in which only a very small part of the oxidation takes place we find the tissues in their relative importance in connection with oxidation to be, the muscles, the secretory glands, the nervous tissue, particularly the grey matter of the brain and the spinal cord then the skeletal tissues whose metabolic activity is very small. In regard to the muscles we find that the chief organic constituent is globulin-proteid. In the case of the secreting glands the chief organic constituent is nucleo-proteid. The globulin-proteid of muscle is less complex than the nucleo-proteid of gland cells, the latter being proteid in combination with certain substances containing phosphorus, which under decomposition produce nucleins, paranucleins, xanthin and phosphoric acid. In the muscles we find the most of the oxidation processes, the heat forming and energy production taking place in connection with muscular oxidation, the chemical action being due to the stimulation of the nervous system. The muscular activity varies; when it is great there being an extensive oxidation going on, resulting in the excretion of CO_2 and H_2O from the body. In the secreting cells of glands the oxidation is not so active as in the case of muscles. This is evident from the fact that while there is a large blood supply passing through the glands during secreting activity, a large proportion of this blood simply flows through the capillaries without any absorption. In the case of the liver, which is the largest body gland, the amount of arterial blood supplied is small, the metabolism of the liver being carried on by the blood which has become largely deoxygenated in its passage through the intestines. In the salivary glands, when the cranial nerves controlling insalivation are stimulated, we find that the blood flowing in the veins is almost purely arterial. Bayliss and Hill have proved that the salivary gland secretion is not accompanied by the production of much heat as was formerly supposed by Ludwig. Ludwig has pointed out that the saliva found in the duct of the submaxillary gland has more oxygen than is found in the arterial blood plasma, indicating that the gland cells do not consume a large proportion of oxygen as they send out oxygen along with the fluid secretion. In this case the oxidation process must be limited. In the case of the liver it was supposed formerly that the blood is warmer than in any other part of the body, although recent experiments have indicated that there is no change in temperature in the liver by the stimulation of the splanchnic or vagi nerves. It is very difficult to measure the temperature of the blood as found in the muscle, because the experiment itself involves during the process a loss of part of the blood heat. It has been found that in leaving the muscles there is an increase in blood temperature as compared with its temperature on entering the muscle. As we found before, in the muscles about one-fourth of the blood in the entire body is found, indicating the extent of the metabolic activity of the muscles. Another one-fourth of the blood is found to be in the liver but the blood

furnished to the liver forms the basis of other changes than those of oxidation, chiefly in connection with glycogen and urea formation.

SECTION V. Proteid Metabolism.

As we have seen the proteid is divided by Voit into two kinds, the tissue proteid and the circulating proteid, or as Schaefer calls them, organized and unorganized proteid, the former forming part of the bioplasm and the latter including the proteid found in the tissue interstices or their fluids, including the blood and lymph. The metabolism of the unorganized proteid may take place in one of two ways, (1) the floating tissue may be incorporated in the tissue before the processes of dissociation and oxidation take place: or (2) the dissociation and oxidation may take place before the incorporation with the tissue, the bioplasm exerting an important influence on the splitting up and oxidation of the unorganized proteid. In the former case the bioplasm is replenished by the unorganized proteid and in the latter case the bioplasm acts upon the protoplasm much in the way that a ferment acts on the substance subject to fermentation. It is generally supposed that in part both of these actions take place in a part at least of the protoplasmic proteid, becoming bioplasm. Voit found that by feeding an animal on non-proteid food and by substituting gelatin for a portion of the non-proteid, less N was excreted from the body, the N from the gelatin being estimated as it is found in urea in the urine. This indicates that less of the body substance is metabolized. As no nitrogenous food was given there must be a certain amount of the body substance metabolized. By giving the gelatin it took the place of this body tissue, thus saving the bioplasm. Voit does not admit that tissue proteids can be metabolized as such, requiring to be severed from the bioplasm first and made circulating proteid so as to be brought to the tissues for metabolism. This however can not be true because there is no chemical difference between the two kinds of proteid, organized and unorganized, and there is no necessity for the removal of tissue outside of the tissue itself in order to metabolism. Liebig takes the opposite view that only tissue proteid can be metabolized so that the floating proteid must first of all become an integral part of the tissue bioplasm before oxidation can take place. It has been proved in connection with the yeast that there may be such chemical action external to the living cells under the influence of cell activity. In addition to this the non-proteid elements do not become assimilated to the tissue substance so as to form an essential part of it and yet they undergo metabolism, the metabolism taking place therefore outside of the tissue substance. The particles of fat, glycogen, starch, etc. can be clearly distinguished in connection with the cells and not forming part of the cell so that they must be oxidized simply under the influence of physical and chemical changes taking place through contact. We may conclude therefore that metabolism takes place both in connection with the organized and the unorganized proteids, the dissolution and oxidation of the tissue proteid and the dissolution and oxidation of the floating proteid, the latter by contact with the tissue proteid. The proteid substances become during the digestive action changed to albumoses and peptones. During the absorption process these peptones are again reconverted into proteids: part of the proteids however are changed beyond the peptone stage into the amides in the intestines, absorbed into the blood and taken to the

liver. This addition of amides to the blood carried through the liver produces an increase of urea in the blood after leaving the liver, the urea being carried to the liver. It is supposed that the amido-acids being broken down into ammonia compounds are then changed into urea. This change of proteid into amide form removes a part of the proteid from the tissue building so that there is involved a waste in the transformation from peptone to amido-acid. This change has not been proved to take place to any appreciable extent in the normal digestive process. The proteid does not possess sufficient carbon to produce this change into amide form. There must be in any case a process of division into CO_2 and ammonia, out of which by synthetization urea is formed. This however represents only a very small part of the proteids. The large proportion of the peptone is absorbed in connection with the mucous membrane and so transformed to proteid form. This transformation takes place in connection with the active epithelium although there is no proof that the change takes placein connection with the cells. We have the analogy of fat synthetization in connection with the cells. It is suggested by some that the white corpuscles which are very numerous and active in the mucous membrane play an important part in the absorption and conversion of the peptones. When assimilated the proteids become absorbed in connection with the blood. There is almost no absorption of peptones in connection with the lacteals and where such absorption does take place to a small extent, absorption takes place in the blood in connection with the mesentery. In the blood of the portal vein therefore we find the absorbed proteid so that it is rich in the serum-albumin or serum-globulin, together with the absorbed proteid extracts and the amides. The portal blood is found to be physiologically different during food absorption from what it is when no food, especially proteid food elements, are absorbed. This difference is resolved into an increase in the amount of urea. Thus the products of digestion, absorption and assimilation are brought to the liver.

Proteid Metabolism of the Liver.—It is possible when the proteid is brought to the liver there may be a storage in connection with the liver cells, before passing to the general circulation, but there is no proof of such storage. The liver secretion consists of nitrogenous matter together with sulphur in organic synthesis. These organic elements are from the proteids and they are increased during the absorption process it is supposed that they are the products of peptone absorption.

Associated with these nitrogenous and sulphurous compounds in the bile salts are the bile pigments which spring from the red blood corpuscles. This seems to indicate that these organic conpounds are formed from the decomposed haemoglobin. Experiments have proved thata larger number of these red corpuscles enter the liver thrn leave it and this seems to favor the idea that in the liver there is a disintegration of at least some of the red corpuscles. In addition to this the blood entering the liver has more water than that leaving it, the bile having taken a part of the water and also the lymph. Thus the liver proteid is more probably derived from the disintegration of the red corpuscles. In connection with the formation and storage of glycogen there may be a source of proteid formation. During absorption there is hardly any glycogen formation, the carbohydrate furnishing the necessary glycogen stored in the liver. When carbohydrate is absent from the food, part of the proteid may become broken down and transformed to glycogen. From the fat of the

food there is an absorption of fat into the liver cells, being metabolized in the mucous epithelium and passed through the lymph and the blood into the liver. When fat is absent from the food the fat found in the liver cells is supposed to be derived from the proteid by a process of division, followed by a synthesis. There may be in case of fat and carbohydrate formation a splitting up of proteid outside of the liver but the liver cells certainly do possess this power of fat and carbohydrate formation. Experiments upon dogs deprived of food have proved that fat and carbohydrate may be formed out of proteid.

The urea and uric acid are formed largely in the liver as may be shown from the fact of the large proportion of urea found in the liver as compared with the other organs; and especially from the fact that after passing through the liver the blood contains an increased amount of urea. The urea of the liver is not to any great extent derived from proteid, because this would involve a nutritive loss. Hence it is concluded that the larger part of the proteid absorbed passes into circulation without any storage in the liver, the excess of proteid being stored in some other part of the body, especially the muscles. This is proved by the fact that when a large proportion of proteid is absorbed the muscle metobolism is increased. As to the way in which this increased metabolism takes place there is a difference of opinion. According to Voit the increased proteid passes in circulating form into contact with the bioplasm, the result of contact being metabolic activity in the circulating proteid. Pfluger holds the view that the increased proteid becomes a part of the tissue substance so that there is an increase of the actual bioplasm, this increase promoting an increased katabolism. Pfluger took the blood of a fasting dog and passed it through the limbs and liver of a dog which had been well fed on proteid and also of a fasting dog. He then reversed the experiment, taking the blood of a well fed dog and passing it through the limbs and liver of a fasting dog. In the case of the blood from a fasting dog passed through a well fed dog there was an increase of urea; in the case of the blood of a fasting dog passed through a fasting dog there was but a slight change in the amount of urea by diminution in some of the experiments; and where the blood of a well fed dog was passed through a fasting dog there was a marked diminution in the amount of urea; in both of these cases there was no proteid metabolism. Pfluger concludes from these that increased proteid causes the bioplasm to grow and produces more active metabolism, while decreased proteid diminishes the bioplasm and reduces the metabolism. That this so seems to be the basis of the theory of athletic trainers, a food being used consisting largely of proteid, the result being an increase of proteid metabolism and the growth of tissue. This does not continue however because very soon the entire proteid absorbed is passed off in the form of urea.

UREA.—Urea is found in the blood in very small quantities, three parts in 10,000. A part of the excreted urea is therefore simply separated from the blood, this separation taking place in the kidneys. The urea thus brought to the kidneys in the blood for separation must have had an antecedent in something else. It is not supposed that all at once the proteid under metabolism becomes urea and the other non-nitrogenous substances. Metabolism is not likely to take place in a single change but rather in a series of changes, this series being different in all probability in different tissues of the body, because the different tissues have different processes and all these seem to converge towards the point of form-

ing the nitrogen in the urea form convenient for excretion. As the proteid transformation to urea does not take place in the liver, at least to a large extent, in its early forms it seems to take place,at least in the initial stages,originally in the muscles in which the oxidation process takes place largely. In this way we have formed some substances which are supposed to represent intermediate stages in the urea formation. In the muscles we find very little if any urea, at least in most animals, so that only a small part of urea if any is formed in the muscles. It has been supposed by some that kreatin formed in the muscles represents the preliminary stage in the urea formation. But kreatin when injected into the blood does not form urea but is found as kreatinin in urine. In connection with the experiments of passing blood from a fasting animal through the limbs of a well fed animal it was found there was an increase of ammonia salts in the blood. Ammonia salts injected into the blood and passed through the liver produce within the liver urea. The ammonia salts are supposed to synthetize with sarcolactic acid produced in muscle. From this it is supposed that proteid when metabolized in the muscles becomes lactate of ammonia and entering the circulation reaches the liver to be transformed into urea and excreted from the kidneys. Experiments have been made of injecting lactate of ammonia into the portal veins of a dog with the result that urea was formed, the remainder being excreted as CO_2 and H_2O. The proteid in muscle is supposed to be divided into nitrogenous and non-nitrogenous elements, being in part at least converted to glycogen which is later oxidized in the tissues. That this division of the nitrogenous from the non-nitrogenous takes place is proved in the case of diabetes where even when proteid food alone is given or when no food is given at all sugar is formed, the formation taking place out of the tissue proteids.

The nitrogenous body metabolism is, therefore, intimately associated with the liver. There is a formation of urea in the liver. It was found by extirpating the kidneys of a dog that the urea formation wasincreased. In passing through the kidneys blood, even containing ammonia carbonate, there was not found any urea increase although the ammonia carbonate can be synthetized into urea in the liver, although some hold that there is a small urea formation in connection with the kidney cells. It has been found that blood passed through muscle, even if it contains ammonia carbonate does not produce urea. On the other hand blood passed through the liver of a recently killed animal that has been well fed produced an increase of the urea. These experiments in connection with dogs and sheep have proved definitely the formation of urea in the liver in connection with ammonia carbonate. The same thing is true of blood containing the absorbed digestive products, ammonia carbamate and lactate and the amides, leucin and glycin. In diseased conditions of the liver, in phosphorous poisoning and when the liver is extirpated the urea is replaced by ammonia salts. The acetate of ammonia as well as the carbonate of ammonia, and the citrate of ammonia given to animals has been found to increase the urea. It is supposed by Drechsel, as we found before, that carbamate of ammonia is converted out of the carbonate by the elimination of a molecule of water, and that the carbamate is converted by eliminating another molecule of water into urea. Thus out of the alkaline salt, carbonate of ammonia, there is formed the neutral urea in connection with proteid metabolism, protecting the body from excessive alklanity and excreting the metabolized product as waste. This seems to indi-

cate the activity of the liver cells in nitrogenous metabolism. This does not mean that the entire nitrogenous metabolism takes place in the liver. Even when the liver is removed or when it is degenerated by disease there is still an excretion of the urea, although it is diminished and it is largely replaced by ammonia salts, although it is not known in what other parts of the body the urea is formed.

In the change from proteid to urea we find three different channels, (1) through leucin and tyrosin in connection with the intestines; (2) through the floating proteid; (3) through the tissue proteid. In each case the center activity is the tissue which while not changing considerably itself changes the proteid that comes in contact with it. It is formed largely in the liver where most of the nitrogenous remnants of the proteids are finally changed to urea. The evidence may be summarized, (1) the fact that a still living liver when excised forms urea from ammonium carbonate; (2) the fact that blood from an animal during digestion passed through an excised liver produces an increase of urea; (3) the fact that in fatty liver degeneration and yellow atrophy of the liver the urea may almost be absent, being replaced by leucin and tyrosin. As to the substances from which it is formed, it is primarily as we have seen from the proteid which is found in every tissue. In the muscles and tissues in general are found a series of bodies containing N, more simple than proteid and less oxidized than urea. Among these are guanin in the pancreas, liver and muscles; xanthin and hypoxanthin in the spleen, liver and muscles; kreatin in muscle and blood and uric acid in the spleen, liver, pancreas and lungs. There is no proof however that any of these lie on the way to the urea in the metabolic process. There is some proof that leucin is a precursor of urea as found in the intestines. In some animals especially birds uric acid instead of urea is the final product of metabolism. It is probable that like the formation of urea the formation of uric acid results from certain substances primarily formed in the muscles, as lactic acid and ammonia, the change to uric acid taking place in the liver. The uric acid is not formed in the kidneys although separated from the blood by the kidneys, for when the kidneys are removed it accumulates in the blood and tissues. Uric acid is not so fully oxidized as urea. In man it is characteristic of a gouty condition that there is an increase of uric acid formation and a deficiency of urea. It is normally present in human urine and is found in the blood, the tissues and spleen. The liver of birds has been removed and in some cases the portal vein has been ligatured with the result that there was a decrease of uric acid in the urine with a large increase of lactate of ammonium. This represents the sarcolactic acid of muscle and as it is found in large quantities the urine in these conditions is very acid. There were found no amides and no sulphates, the kreatin and urea being unchanged. When the hepatic artery is ligatured in birds the uric acid is found to be replaced by lactate of ammonia, on account of the interference with the liver activity preventing the change to carbonate of ammonia and uric acid. The uric acid in mammals is different. It does not increase in connection with proteid food nor do we find it in any sense dependent upon urea excretion. The giving of ammonia salts or the amides to mammals does not produce uric acid. The proteid metabolism of mammals is very different, therefore, from that of birds and reptiles, the difference being found in connection with the liver, the substances formed in the muscles being the same. Experiments have shown that dieting upon gland substance, especially the

thymus gland produces in mammals an increase of uric acid. This represents the nucleo-proteid. It has been found also that where the lymph cells and the white corpuscles are greatly increased there is an increase in uric acid. It has been found that during active digestion when the glands are very active uric acid is increased. The same result is noticed in connection with the use of pilocarpin. When the liver is in a condition of cirrhosis the uric acid is decreased so that it is not found in the liver, having reached the kidneys without passing through the liver. It is supposed that by the disintegration of nucleo-proteid in connection with the glands and the spleen there are formed proteids, phosphates and xanthin, the last being oxidized in the production of uric acid. By the oxidation process one molecule of uric acid can be divided into two of urea and one of some carbon acid. This does not indicate that uric acid is a precursor of urea, for the facts prove that it indicates metabolism of a different character, the divergence taking place at the end of the process. The cause of this difference is found in the fact that urea seems suited to go itno a fluid excretion and uric acid into a solid excretion. The uric acid represents a synthetic condition in which some other substance takes part, as for example, the combination of glycin and urea forming uric acid. On account of the constancy with which it is found in the spleen and its variation changing with splenic activity, it is supposed to be formed in the spleen. This however is subject to the fact that in the liver the final turn is given to it so as to form it into uric acid

In regard to guanin, xanthin, hypoxanthin and kindred substances in their relation to metabolism little is known. They indicate the complexity of the proteid metabolism. As we saw urea may be formed finally in different ways. This may account for the fact that in the metabolism there is such a complete splitting up of substances into simpler forms. Some of these appear in simple form in the urine whether on account of imperfect metabolic action or because they are essential in these forms to the metabolic process is not known. When the proteid matter acted on by tripsin or by chemical substances produces leucin, tyrosin and other substances accompanies it in the dissolution. Tyrosin is thus a constant element in decomposition, and this seems to indicate in proteid composition some aromatic substance which forms the basis of benzoic acid furnished for the formation of hippuric acid. It is claimed, as we have seen, that nitrogenous matter in the bioplasm appears in the cyanogen compound form, in the transformation to dead tissue the cyanogen compound being transformed into an amide. Confirmatory of this idea is the fact that ammonium cyanate by heating may be converted into urea. In addition to this sulpho-cyanates are found in the salivary secretion and in the urine and kreatin can be produced from sarcosin as found in the blood and cyanamide. From all these facts the metabolism of proteid is very complex on account of the large number of nitrogenous substances appearing in the body at different stages of the metabolic processes.

SECTION VI. Carbohydrate Metabolism.

In digestion the carbohydrates are converted chiefly to maltose, this being changed to dextrose in absorption, the dextrose being the only sugar form found in the blood and in the tissue fluids generally. In the absorption process the dextrose is taken up by the blood, carried in the portal circulation to the liver and stored there. It is in the portal blood

alone that an excess of dextrose is found during digestion, between the digestive periods the portal blood loses this excess of sugar. The blood in the hepatic vein does not contain during the absorption process so meuh sugar as the blood of the portal vein. From this it is concluded that sugar taken to the liver is kept in the liver in some way. Experiments seem to indicate that after a meal consisting largely of carbohydrate there is an accumulation of glycogen in the liver. If in the case of an animal fasting dextrose is injected into one of the mesenteric veins there is also an accumulation of glycogen in the liver. Laevulose or dextrose injected subcutaneously also causes glycogen production. If blood rich in dextrose is passed through the liver of a dog, glycogen is also produced in the liver. The glycogen found stored in the liver does not account for all the glycogen production arising in connection with carbohydrate food, so that a part must go through the liver into the general circulation and be stored elsewhere. The muscles seem to take up part of the glycogen as about one per cent of glycogen is found in normal muscle, the liver having been found in some cases to contain as much as seventeen per cent. Taking this amount stored in the muscles and liver we find that it does not represent all the carbohydrate taken in connection with the food. Even when we add the sugar floating in the fluids it does not represent all the carbohydrate of the food. Part of the sugar may enter into the proteid, albuminoid or nucleo-proteid composition, so that it is stored in this compound form until required. Glycogen is found in large quantities in the placenta and in the embryo, chiefly in the growing muscles. During starvation the glycogen gradually passes from the liver and muscles. Muscular exercise assists this glycogen consumption so that glycogen is used up in the production of energy and also of heat. In different animals we find that during starvation the glycogen disappears with different degrees of rapidity. In horses it has been found after a fast of ten days, in dogs after twenty days, while in rabbits it is usually gone within seven days. In the hybernating animals and frogs it accumulates during the summer in the muscles and is used up during the winter. When muscles are active the glycogen is lessened. After tetanus the glycogen is found to be diminished and in some cases it disappears, as it does in the case of excised muscle when it becomes rigid. It is not known what becomes of it as the sarcolactic acid does not depend upon the glycogen. It has been found that if the nerve going to a muscle is cut the glycogen is increased.

Glycogen can be produced even when carbohydrates are absent from the food. For example, when animals are fed on pure proteid, as lean meat, there is found, even in the absence of carbohydrates from the food glycogen in the muscles and liver. By causing an animal to work and at the same time to fast so that all the glycogen may be exhausted, and then feeding it on proteid food the glycogen will be found in the liver and muscles. Under the same conditions the giving of chloral will produce glycogen, the formation taking place from the body proteids. When fat is given alone or along with other food there is no production of glycogen. The use of glycerine seems to prevent the using up of glycogen and the use of ammonium carbonate assists in the accumulation of glycogen in the liver. In the formation of the embryo chicken there is accumulated a large quantity of glycogen, although the egg contains little glycogen or carbohydrate, so that the production must take place from proteid by a synthetic process, preceded by the dissolution of the proteid particle. It

is suggested that in this synthetic process the dextrose represents one of the stages, and as dextrose is the blood form of sugar it is probable that it represents the stage of carbohydrate metabolism which is always reached in connection with its use in producing body energy and heat.

A large proportion of the food under the process of absorption passes into the liver before it reaches the general circulation. There are therefore important metabolic changes that take place in connection with the liver. The liver performs various functions. We have already discussed (1) the formation of bile. In addition to this (2) the conversion of certain substances, for example, kreatin and leucin into urea; (3) the breaking down of the red blood corpuscles, the coloring matter being utilized in the formation of bilibrubin; (4) the formation of fat, and (5) the formation of glycogen. The formation of glycogen is closely connected with the nutritive processes and marks the changes taking place in connection with the different tissues. The discovery of glycogen formation was made by Claude Bernard when he found after death in the liver a quantity of sugar. In later years he investigated the subject proving that in life glycogen is formed in the liver and that this takes place under the influence of a diastatic ferment the glycogen freely changing into sugar. In studying digestion and absorption we found that a quantity of sugar is carried as a result of these two processes by the portal system from the alimentary canal to the liver. If an animal is killed it is found that after a short time the blood in the hepatic veins, that is, the blood which has passed through the liver, contains much more sugar than the blood in the portal veins, that is the blood that has not yet circulated through the liver. If the liver of a freshly killed animal, rapidly taken from the body, is cut in peices and thrown into a vessel contaning boiling water, the infusion is found to contain little or no sugar. If, however, the liver is kept for a short time at a moderate temperature of 15.5 degrees C and then cut to pieces and thrown into boiling water the infusion will be found to contain a quantity of sugar, the amount of grape sugar being proportional to the length of time the liver is kept before being put into boiling water. There goes on then in the liver a process, at least after death, which results in the formation of grape sugar. What is the source of this glycogen? If the opalescent sugarless infusion made from the liver immediately after death is treated with salival ferment or any other ferment which has the power of converting starch into sugar the infusion is found to become clear and to contain a considerable quantity of sugar. The source of this sugar is evidently some starchy body. When this opalescent infusion is treated with alcohol a white amorphous powder is obtained. It has the composition $C_6H_{10}O_5$ is a carbohydrate and may be rapidly converted into sugar by the action of dilute mineral acids. It is called glycogen and by some has been called Bernardin after its discoverer. This substance is evidently present in the liver and probably by the action of some ferment becomes converted into sugar after death. The amount of glycogen varies in different animals. It exists in largest quantities a few hours after a full meal. It is lessened by fasting and it may disappear altogether by a prolonged fasting. That it is one of the life substances is evident from the fact that it disappears after death being converted into grape sugar. If an animal is starved the glycogen present in the liver gradually diminishes in amount and through time it will disappear entirely. When a diet rich in carbohydrates is used abundance of glycogen is found in the liver. If carbohydrates are withdrawn from the food and the animal is fed on proteids alone

there is still found some glycogen. The amount of glycogen is influenced by the character of the food. The carbohydrates are transformed into maltose and the maltose passes into the portal circulation. If glucose is injected into the portal circulation it is found that the glycogen formation is increased. The formation of glycogen also is increased by the use of food rich in starch, grape sugar or any other kind of sugar. Even the albumin in the liver may be divided into a nitrogenous and a non-nitrogenous element, the latter becoming glycogen. Fats do not influence the amount of liver glycogen. It is evident that the chief source of the glycogen is the carbohydrate taken as food and this as we have seen reaches the liver in the form of dextrose. In this way the very soluble carbohydrate substances are converted into the less soluble and stored up in the liver cells for the use of the tissues of the body when no fresh nutriment can be derived from the alimentary canal. The glycogen becomes transformed into glucose under the influence of a ferment found in the liver, the conversion being arrested if the liver is placed in a temperature at or above 100 degrees C or at or below O degrees C, the extremes of heat and cold coagulating the ferment. Glycerine extracts from the liver transform starch into sugar, the glycerine extracts of some other organs having at times the same effect. The glycerine extract of muscle has always this effect. The existence of sugar in the blood of patients subject to diabetes has long been known but it is only recently that the relation to glycogen has been understood. The amount of sugar depends upon the nature of the food. When the amount is largely increased the kidneys separate it from the food and the condition is known as diabetes, a pathological condition in which a large quantity of sugar is found in the urine, due as we have said to the presence of a large proportion of it in the blood. If the medulla of a well fed animal, for example a rabbit, be punctured in the region of the vaso-motor center, it will be found in the course of an hour or two that the urine has a considerably increased quantity of sugar. The more rich the liver is in glycogen, in other words if the animal is well fed, the results will be more marked. If on the other hand the animal is starved the urine will be found to contain no sugar or almost none. The puncture in the medulla causes the profuse discharge of the sugar from the liver, until it becomes exhausted, for the urine will continue to exhibit a marked increase in the proportion of sugar until a maximum is reached after which the urine will be normal. It was formerly supposed that the sugar was completely oxidized in the lungs, on account of the oxidizable nature of the glucose, particularly in the alkaline blood. This however is proved erroneous by the discovery of the fact that the amount of sugar in the blood at the left side of the heart is not smaller than that found in the blood on the right side of the heart.

In addition to this sugar is found in the blood in connection with all the body tissues particularly in the muscles. Muscle also contains glycogen or animal starch. Muscle contains glycogen even after being deprived of food, the muscular action of the tissue using up the glycogen not only as found in the tissues but also as stored in the liver. The glycogen converted into sugar is first used up by the muscles and it is used in the tissue-building. Under the influence of curare diabetes may be induced resulting in paralysis of the muscles of voluntary activity, on account of the fact that the inactive muscles do not use up the sugar, the sugar accumulating in the blood and being excreted in the urine. This however

is perhaps better explained on the basis of paralysis of the vaso-motor center. While there is no doubt that after death blood, if made to circulate through the liver, contains more sugar in the hepatic vein than in the portal vein, it is not settled as to whether the same condition exists during life or not. Different observers have given different results. Those who hold that no more sugar is present during life in the blood of the hepatic vein than in the blood of the portal vein regard the glycogen as one of the stages of a process which consists in the conversion of carbohydrates and perhaps even of proteids by the liver into fats. Almost all the evidence in favor of this idea is the fact that oil globules, sometimes in great abundance, are found in the hepatic cells. The formation and presence of glycogen in the liver are according to this view to be regarded merely as a step towards the formation of another substance, namely the fat. The theory opposed to this is that the glycogen in the liver is a store of carbohydrate matter which can by the conversion of the glycogen into sugar be drawn upon by the economy of the system when digestion is not going on, that is, when no carbohydrates are being furnished to the blood from the alimentary canal. The sugar and starchy substances of the food which result from the process of digestion and absorption pass into the blood of the alimentary canal as grape sugar and as such are conveyed to the liver. Part of this grape-sugar passes at once into the circulation, supplying the immediate necessities of the bodily system, the excess being stored in the liver, dehydrated and stored as glycogen. The amount present in the liver varies depending upon the food, the amount of exercise, and body heat. The varation lies between one and four per-cent of the liver weight. If the diet is largely carbohydrate this is increased. In the dog it has been found to rise to 17 per-cent and in man to 10 per-cent. The glycogen exists in the liver cells being found by microscopic examination in connection with the liver bioplasm. It is easily detected being soluble in water and opalescent in solution, in reaction with iodine solutions giving a characteristic port wine color.

When food is not supplied to the alimentary canal there is no carbohydrate matter furnished to the blood and it is then that the stock of glycogen stored in the liver is drawn upon. In this way the regular supply of carbohydrate is furnished to the body system. In favor of this idea is the fact that the amount of sugar in the blood is constant, remanining almost the same when the food is being taken as in the interval between meals. It would seem that the function of glycogen in the liver is for the purpose of supplying a stock to be converted into sugar and to pass into the blood. The question arises, what is the function of this sugar. It was at one time supposed that the sugar furnished to the blood by the liver was oxidized in the passage of the blood through the lungs. This however as we stated before is incorrect. This was based on theanatomy of the circulation and also on the fact that glucose in an alkaline medium like blood is very easily oxidized. Hence the theory that when it reaches the general circulation it is distributed to the tissues of the body, especially to the muscles, seems to be generally accepted. In this way there are furnished to the muscles the necessary materials required for muscle contraction, so as to maintain the contractility of muscle. This is proved by the fact that sugar exists in the blood circulating in all tissues.

It is found in all muscle varying from one-half to one per-cent. Even

when deprived of food muscle contains glycogen. It is supposed by some that the muscle really performs the same function as the liver, namely withdrawing sugar from the blood and converting it into glycogen, the muscle forming in itself a small store house of deposited carbohydrates which can be drawn upon according to the requirements of the muscles. The muscles draw upon the stored-up glycogen in the liver. When muscle contraction takes place the amount of glycogen is diminished. It is generally held now that when the glycogen is changed to sugar it is used up in the muscles and that it is necessary for the muscle anabolism and to maintain muscle contractility. It is also held that by withholding all carbohydrates there is a fall of temperature, indicating that sugar is necessary for body heat. It is certain that sugar is essential for the tissue upbuilding the glycogen being found in great abundance in embryonic and growing tissues. If the muscle becomes tetanized then the amount of glycogen is diminished. Although we have proof of the existence of a ferment in connection with the liver after death, this does not prove that such a ferment exists during life, any more than fibrin in shed blood would prove the existence of the fibrin ferment in living blood. Aside from the question of the existence of the ferment, there still remains the difficulty of explaining how in the presence of such a ferment glycogen could be stored up in the liver, and why that ferment appears to have such a strong effect immediately after death.

From the fact that the puncture of the vaso-motor region of the medulla produces paralysis of the hepatic vessels, it has been concluded that the increased flow of arterial blood through the liver which results in the formation of sugar or its appearance in the urine and that the ferment which converts the glycogen into sugar is conveyed to the liver by the arterial blood. The fact is apparent that the presence of a large proportion of arterial blood in the liver increases the transformation of glycogen into sugar. Claude Bernard first found that the puncturing of the floor of the fourth ventricle at the source, of the vagi nerves and corresponding with the vaso-motor center, resulted in sugar in the urine, caused, by a change of glycogen in the liver to sugar. The vessels in the liver are found to be over-filled with blood, this being due to vaso-motor paralysis in the liver. This is called puncture diabetes. If the liver is first of all exhausted of its glycogen by starvation, there is no glycosuria in this case of puncture. It is probable that this puncture interferes with the hepatic circulation, especially in the hepatic artery altering the liver metabolism. Others suggest that it is due to the immediate interruption of the nerves to the liver. It may be due to the lessening of the amount of oxygenated blood going through the liver, exciting the hepatic cells and producing increased activity in the metabolism. The same condition may be produced by phosphoric or hydrochloric acid, strychnine, arsenic and phosphorus. It has been found also that temporary diabetes may result from an injury to the cerebral lobes, to the cerebellum, to the white cords outside the corpora albicantia to the pons Varolii, to the middle parts connecting the cerebellum, the cervical sympathetic and sciatic nerves and the brain above. The vaso-motor nerves to the liver pass from the center in the medulla along the spinal cord, passing into the sympathetic through the splanchnics into the liver. In leaving the spinal cord they pass, along in company with the vertebral artery, passing thence to the lower cervical ganglion. From this ganglion they proceed by division around the sub-clavian arteries constitut-

ing the annulus of Vieussens, proceeding thence to the first dorsal ganglion and through the sympathetic and the semi-lunar ganglion to the hepatic vessels of the liver. If a division is make of any of these nerve connections the liver paralysis ensues, followed by dilatation of the blood vessels and the increased production of sugar. Cyon has pointed out that for the increased formation of sugar it is necessary that there be an increase in the blood flow. This increased blood flow may be effected, either (1) by the direct paralysis of the vaso-motor center, or (2) by the inhibitory action of the sensory nerves upon the vaso-motor center. If the vagus is divided and the cephalic end be subjected to stimulation the liver increases in activity on account of the increased blood flow through it. In this case the vagus exercises an inhibitory action upon the vaso-motor center. (3) The same effect may be produced reflexly by the stimulation of the pneumogastric in its terminal branches in the liver or lungs, in the main trunk of the pneumogastric or at its roots in the medulla.

It has been found that the division of the sympathetic between the 10th and 12th ribs does not produce sugar in the urine. Cyon explains this by the fact that in addition to the dilatation of the liver vessels there must be an increased blood flow to produce sugar accumulation. The blood increase is the important point. The intestinal vessels when dilated can hold as much blood as all the other vessels of the body, the lower part of the cord and the splanchnics supplying vaso-motor fibres. If these are severed the intestinal and hepatic vaso-motors are paralyzed, dilatation of the vessels takes place so that so much blood is retained in these vessels that no blood can be sent to the liver to increase its circulation. If the hepatic vessels are dilated and after the cord and splanchnics are divided, the formation of sugar takes place, because the circulation through the liver has been first firmly established. The vessels of the liver may also be dilated by the inhibition of the vaso-motor centers through the sensory nerves for example, the sciatic or the vagus. By cutting the vagus in the neck and stimulating the upper end hepatic dilatation follows and sugar is found in the urine. Here the vagi through some of their fibres inhibit the vaso-motor center. Wherever the liver blood pressure is increased there is an increase in sugar production. It is inferred from this that the substances which form the ferment for glycogen formation are carried to the liver by the hepatic artery. Pavy thinks that whenever a larger supply of arterial blood passes through the liver than normal there is the production of glycosuria. By injecting defibrinated arterial blood into the portal vein he found an increase of sugar in the urine, so that whenever the blood becomes over-oxygenated or over-carbonated the blood so influences the glycogen as to produce sugar.

Glycogen is found in other parts of the body besides the liver. The skeletal muscles particularly manifest the presence of glycogen, so much so that it becomes an almost invariable element in connection with muscle tissues. The amount varies in different muscles and also in different animals. It increases when the nervous connection is cut off from the muscles, and it is lessened, passing into dextrose when the muscles become rigid. It is not however a necessary constituent of muscle in the regular muscular metabolism, because muscles possess the contractility characteristic of muscle even without glycogen. It is found that in embryonic life the muscle is very abundantly supplied with glycogen, the

glycogen gradually being diminished as the process of striation proceeds. In this case the large proportion of glycogen is stored in the muscles so as to accelerate the rapid embryonic changes from the simple cellular protoplasm to the striated muscle. It is this fact that helped to formulate the conclusion that the same function is discharged in the adult life, the carbohydrate matter being so stored up as to be immediately at hand as available material in the muscular metabolism. Glycogen is also freely found in connection with the placenta in which it is found in connection with the epithelial cells that mark the separation of the foetus from the mother. In this case it discharges the same function, providing a store of carbohydrate material for the nourishment and upbuilding of the foetus. In the metabolism of the body from its earliest stages during the entire period of existence glycogen plays a most important part in connection with body development.

In regard to the carbohydrates, whether they pass through the glycogen stage or not, they finally become oxidized in the form of CO_2 and H_2O to be excreted from the body. When carbohydrate is given in the food the CO_2 given off is increased. The CO_2 production takes place gradually out of the stored up matter in the liver changed from carbohydrate. It is in the dextrose form that it is carried to the tissues and oxidized. The oxidation takes place either in connection with proteid metabolism, by becoming part of the bioplasm and then being split up and oxidized: or else by being brought into contact with the bioplasm. Some claim that all body energy is derived from carbohydrate oxidation. The carbohydrate is carried to the tissues by the blood, being formed either from the fat or proteid in connection with the liver cells or else in connection with the carbohydrate stored in the liver cells. This goes on the supposition that metabolism consists of producing and destroying carbohydrate in some form. Seegen holds that this is so, contending that even the proteid in its non-nitrogenous elements become converted to carbohydrates before its oxidation takes place.

The theory of Bernard is more acceptable. He found that there is a constant passage of sugar from the liver to tne tissues through the hepatic blood, even when an animal is deprived of food, except at the very close of a long starvation period. The hepatic blood always contains sugar no matter what the food may be, proteids, fat or carbohydrate. Seegen claims that the hepatic blood always contains more sugar than the rest of the blood in the body. Seegen's experiments do not take account of the fact that the infliction of pain upon an animal produces the change of glycogen into sugar. He himself admits that when pain is removed by administering anaesthetics there is a very slight difference between the hepatic blood and the normal arterial blood. Pavy has more vigorously assailed the Bernard theory He killed an animal by a stunning blow on the head and immediately took blood from the hepatic circulation before there was time for any hepatic change. He finds that the blood coming from the liver does not show any variation, or only very slight, in the substances reduced to sugar form over the rest of the blood. These contradictory results leave the question unsettled. If the hepatic blood contains a large proportion of sugar, then it implies the constant passage of sugar from the liver to the general circulation for the nourishment of the tissues and to be oxidized in producing energy. If it does not contain an excess, then the glycogen we have found stored in the liver becomes exhausted and this explains how it is found in the muscles. Pavy concludes

that the glycogen stored in the liver and muscles becomes converted into fats, which enter the circulation and are carried to the different tissues of the body to be oxidized.

Another theory suggests that it is immediately oxidized and produces energy and heat. It is probable that the glycogen passes from the liver to the muscles from the fact that the chief oxidation processes take place in the muscles and that the glycogen remains longer in the muscles than in the liver under starvation. The transference from the liver to the muscles cannot be in the pure glycogen form, because the blood plasma does not contain glycogen, the leucocytes containing all the glycogen found in the blood. It is this fact that leads to the theory of its conversion into sugar form before leaving the liver. It is difficult to estimate the amount of sugar in the blood, the estimates that have been formed being imperfect, because the basis taken has been the reduction of the cupric salts. There are other substances that effect this reduction aside from sugar. Hence, we may say that it has not been determined what amount of glucose has been found in the blood. The theory of Bernard, therefore, rests rather upon analogy and indirect than upon direct evidence.

The strongest proof is found in the fact that dextrose is formed out of glycogen in the liver under the influence of nervous stimulation, by artificial interference with the hepatic circulation as well as under the influence of certain poisons and by the preservation of body temperature in the liver after death. The glycogen is stored up in the liver for the purpose of supplying the carbohydrates gradually for normal use. As the carbohydrate forms the bulk of the food, the regulation of its supply to the tissues is an important matter. On the other hand, when the activity of the liver cells is destroyed after death, or when chemical action is arrested this change to sugar does not take place. Noel Paton finds that when the liver cellsare crushed in a mortar there is no change from glycogen to sugar. Bernard solved this by stating that the transformation takes place under the action of an amylolytic ferment derived from the blood This is denied by Dastre and others who state that 55 degrees C is sufficient temperature to destroy the ferment and that the same thing is true of exposure in an ice cold sodium salt solution. It is contended that the action is not due to a ferment but to cell protoplasmic activity. It is claimed that in the case of the action of the amylolytic ferment maltose and not dextrose is produced, while in the liver activity glycogen is changed to dextrose. The most recent experiments of Pavy and others have shown that a powerful ferment can be derived from the liver of rabbits hardened in alcohol, the sugar found being dextrose although it may be mixed with maltose, the conclusion being that it is derived from the ferment found in connection with the blood and lymph. The glycogen is reconverted to dextrose, in all probability, by the activity of the liver cells in metabolism. Pavy strongly denied that under any normal conditoins sugar formation takes place in the liver the sugar found in the liver and in the hepatic blood being due to post mortem action. If,as is claimed, the sugar transformed in the liver is carried off quickly by the blood, then in reality there is no sugar in the liver as it is taken off as soon as formed. Neol Paton in the Journal of Physiology, September 1897, cites a large number of experiments in which he claims that there is direct proof of the fact that there is not developed after death an amylolytic enzyme in the liver, but that

the experiments prove that the change from glycogen to glucose takes place under the influence of the active katabolic changes taking place in the liver cell. He claims that enzyme action and katabolic cell activity are analogous, the ferment action being due to certain forms of motion associated with matter. Here the katabolic side of the metabolism prevails. Pavy and Tebb both defend the view that there is a liver ferment and that it is under its action that the transformation of glycogen to dextrose takes place.

By giving successive doses of phloridizin, which is a glucoside, or phloretin or by the subcutaneous injection of these there are found in the urine large quantities of dextrose, the glycogen being decreased in the liver, even when the animal is fasting or fed on proteid alone. Part of the sugar may come from the phloridizin itself but this can not account for the quantity nor can it account for the same result from phloretin. It requires successive doses to extract all the glycogen from the liver and muscles. Even after all the glycogen has been removed from the liver, the administration of doses of these substances will produce sugar in the urine, the tissues being drained and then if the substances are still given the proteid metabolism produces sugar. That this is so is proved by the fact that the nitrogenous elements of the urine are correspondingly increased with the sugar. If by fasting and exercise the glycogen is exhausted, the administration of phloridizin will produce sugar in the urine, in this case from its quantity seeming to arise from tissue proteid dissolution. Even if the liver is rendered useless the administration of phloridizin will produce sugar. This seems to indicate the immediate formation of sugar from proteid without the formation of glycogen, as in acute diabetes where the product of proteid metabolism seems to be carbohydrate formation and sugar which passes directly to the blood. Some physiologists claim that sugar formation in these cases takes place in the kidneys as it has been found that if the renal blood vessels are ligatured no sugar accumulation takes place in the blood. Minkowski claims that phloridizin is divided up in the kidneys into phloretin and sugar, the sugar being excreted and the phloretin being synthetized with sugar again. Diabetic conditions may also be produced by the use of curare, even in the frog where there is no interference with respiration as there is in other animals.

The pancreas has an intimate relation to carbohydrate metabolism. Mering found that by the total excision of the pancreas the diabetic condition resulted. It was at first supposed that this was due to the action of the nervous system rather than the pancreatic action. Minkowski confirmed the experiments of Mering on the cat and dog, proving that the removal of the pancreas resulted in acute diabetes, represented by a large water excretion and the presence in the urine of sugar and a number of acids. It was shown by further experiments that this was not due to the lack of gland secretion, and also that if a portion of the pancreas, even a very small portion and even if it is removed from its normal position, is left the sugar accumulation does not take place. Many recent experiments have confirmed the fact that by the removal of the pancreas there is immediately a large increase of sugar in the blood and urine. This represents the same condition so far as the blood is concerned as puncture diabetes, namely, an increase of the sugar in the blood. Accompanying this is the disappearance of the liver glycogen. Even when carbohydrate is withheld from the food this sugar continues to be excreted,

being derived evidently from the proteid metabolism. The pancreas seems to assist carbohydrate metabolism either by aiding in the formation of glycogen in the liver or by aiding in the dextrose oxidation in the tissues. In both cases the dextrose will be prevented from accumulating in the blood. In what way the pancreas does this is unknown. The pancreatic diabetes is not of necessity the result of the change from glycogen as the diabetic condition continues even after the glycogen is exhausted and even during the existence of glycogen the sugar is too excessive to be accounted for in this way. Some think it is due to the absence of the ferment from the blood, the glycolytic ferment being formed according to Lepine and Harley in the pancreas. The pancreatic diabetes is not hindered by feeding the pancreas in food nor does it seem that any poison in the blood produces the diabetic condition, as the diabetic blood of one animal does not produce diabetes in a normal animal. It must therefore depend upon the withdrawal of some substance furnished by the pancreas. Schaefer suggests that it is due to the formation of a substance in the peculiar cells of the pancreas which are richly supplied with blood vessels and have no connection with the alveoli. This is the only physiological difference between the pancreas and the salivary glands and as the salivary glands have no influence upon metabolism, this seems to be a reasonable theory. In the case of diabetes when the body becomes overcharged with stored up carbohydrate it has been found accumulatied in the brain and in the glands of the body. This seems to indicate that glycogen is stored up in the normal conditions so that it can be drawn upon when required by the tissues. By giving arsenic in sufficient quantities to an animal the opposite effects may be produced, preventing glycogen accumulation in the liver and tissues even when carbohydrate food is taken freely. The arsenic seems to act upon the hepatic cell substance in such a way as to prevent the formation of glycogen. Glycerine has the effect of retarding the conversion from glycogen to sugar, having the effect of increasing the storage of glycogen in the liver.

In regard to the origin of glycogen, the main source is normally the carbohydrates. By giving an excess of carbohydrate in the food the glycogen may be increased excessively. The glycogen is formed from dextrose, laevulose, maltose and saccharose, either directly or from some intermediate substance during digestion and absorption. The sugar reaches the liver mainly in the dextrose form, the transformation taking place in the hepatic cells into glycogen. The di-saccharines require to be subjected to inversion during alimentation in order to be in form for assimilation. The lactose does not readily become changed to glycogen as if taken largely in diet it is excreted in the urine, indicating that an excess can not be stored in the body. Hence dextrose and laevulose freely produce glycogen, however they reach the liver; maltose only if absorbed from the alimentary canal; lactose and galactose do not form glycogen, perhaps because not fermentable. This has an important bearing upon milk diet, as in childhood and the growing individual it seems to be very easily assimilated. That the proteid produces glycogen is proved from the fact that by giving proteid alone or proteid and gelatin the glycogen formation continues, although not so extensively as in the case of carbohydrate food. The greatest amount of glycogen is formed when a mixed diet is taken with a large quantity of carbohydrates. This is of importance because glycogen containes no N and it therefore indicates the breaking up of the proteid into nitrogenous and non-nitrogenous elements, the

non-nitrogenous forming the glycogen. This explains the fact that in diabetes even when the carbohydrate is withheld sugar appears in the urine. There is no glycogen formation from fats.

In the hepatic cells of a frog, Foster says, that three kinds of materials are found, oil globules, small proteid granules and a hyaline substance of a transparent character in the outer portions of the cell close to the blood vessels. By the use of water this last substance can be dissolved out of the cell substance and with the iodine solution it gives the port wine color. This, he says, is glycogen in a loose combination with other substances. If the frog is fed largely on carbohydrate the cells become swollen, the meshes of the cell substance being filled up with this hyaline substance in its outer parts. If instead of carbohydrate proteid food is given almost entirely then a very little of the hyaline substance is noticeable. If no food is given at all and if the temperature is raised considerably above normal the cells are found to be almost entirely free from this hyaline material, the cells being very small, less than half the ordinary size. The same changes are found in the liver cells of mammals, the hyaline matter when present occupying a place nearer to the center of the cell. These represent processes taking place in the hepatic cells that are very complicated, if we add to the glycogen formation the fact that the bile elements are being formed and passed into the bile ducts at the same time. This indicates clearly the hepatic cell function of manufacturing and storing glycogen in its own substance to remain there till drawn out again into the blood. The double process is that of hydration from animal starch to sugar and dehydration from sugar to animal starch, in the latter case the liver cells taking the sugar as it circulates through the hepatic capillaries and de-hydrating it to form glycogen.

SECTION VII. Fat Metabolism.

Fat globules are found in the cells of muscle and nerve tissue and in the white corpuscles. The medullated part of the nerves also contains a large proportion of fat. Fat that is absorbed cannot exist in any other form than fat. It becomes oxidized, producing CO_2 and H_2O as final products. It may be oxidized at once or it may be stored up as a reserve for oxidation when required. Thus the fats are either consumed or form adipose tissue. When the fat passes through the lymph to the blood it passes rapidly from the circulation as very little is found in the blood except during digestion. The connective tissue cells are filled at certain times and in certain parts with fat, the cells of the tissue becoming fat masses. This is called the adipose tissue which is found in different parts of the body. Some of the organs of the body are encased in such tissue, as the kidneys. The large proportion of the adipose tissue is found, however, subcutaneously as the panniculus adiposus. Adipose tissue changes more freely than any other body tissue, this being the first part of the body to yield when there is a deficiency of food and also the first part to increase when the food becomes too rich or plentiful. In this adipose tissue we find the cells filled with fat, the cell being greatly enlarged and the cell substance becoming thick at the nucleus and very thin in the rest of the cell, forming almost a signet ring shape the stone representing the nucleated portion. These cells are bound together by connective tissue. In the embryonic form of adipose tissue we find small nucleated cells of irregular shape. Gradually the fat accumulates in the cells, the cell increasing in

size and the cell substance being exhausted in the process of fat accumulation, the remnant of the cell substance being collected around the nucleus at one end of the cell. The fat thus accumulated gradually disappears in connection with the lymph and blood, the cell being diminished in size and the interior being occupied by lymph which is later absorbed, the cell decreasing to be followed by a process of renewal in which the cell divides to form two new cells, these again forming fat cells. This process goes on continuously in connection with the adipose tissue.

As we found before, the fat of the body is not derived from the fat taken as food, at least to any great extent. There is a difference in the composition of fat and hence fat taken as food is changed before it becomes part of the tissue. The fat found in adipose tissue consists of differing proportions of olein, stearin and palmitin, together with the glycerine compounds of the fatty acids, the lecithin and cholesterin. The difference in different animals consists of varying proportions of these three fats, the variation being represented by the capacity for melting. In man the subcutaneous adipose fat will melt about 20 degrees C, while that around the kidneys will not melt till 25 degrees C. In man the adipose tissue contains largely olein which is difficult to dissolve, while in the sheep we find stearin which is easily melted. To diet a man upon mutton involves the transformation of stearin to olein fat. This implies the change of the food fat into body fat, in other words there may be a part of the fat capable of assimilation to the body tissue at once but the larger proportion requires to be broken down and oxidized, the products of these processes being built up into body fat. It has been proved in the case of dogs which have been deprived of food for a considerable time till the body fat is exhausted, that if they are fed upon a large quantity of mutton fat along with proteid, very quickly they take on fat of the same character as that of the sheep. This seems to indicate that temporarily a large part of the fat is simply added on to the body substance. The same thing has been proved by feeding dogs upon linseed oil and spermaceti, these forms of fat which are foreign to the animal system being taken on in the body. We have seen that fat absorption takes place in the fatty acid form, the fats being broken up under the influence of the pancreatic ferment into fatty acids and glycerine. During the absorption process in connection with the epithelial cells of the intestines the fatty acids become synthetized along with glycerine in the formation of fats. The epithelial cells are filled with the fat particles, the synthesis taking place in connection with the cells, the cells having the capacity of producing glycerine in case of its absence from the food. The fat is said by some to be brought to the fat cell in the form of fat and to be simply placed in the cell substance. Others think that the cell has the power of making fat from other substances, the process being one of cell feeding so as to build up the cell substance. It is certain that in the case of the formation of fat out of proteid the metabolic process goes on in connection with the cell. At the same time the fat which is absorbed from the alimentary canal seems to be carried by the white corpuscles to the tissues, depositing it in the adipose cells. As only a small part of the body fat comes directly from the fat of food this cannot be the case with the bulk of the fat formation. Liebig pointed out that the fat of butter was much larger than the fat of food, whether in connection with grass or dry feeding, in the case of a cow. If the fat is derived from other sustances then the fat must be formed from other substances that are not fat and there

must be cell activity. This leads us to examine into the formation of fats from other substances taken in the food, namely the carbohydrate and proteid.

Next to the fat of food comes the carbohydrates which are recognized as an economical and valuable fat producer. The feeding of animals upon grass in which there is very little fat or proteid produces fat very quickly. Voit in opposition to this holds that carbohydrates do not directly produce fat but protect and spare proteid oxidation, permitting the non-nitrogenous proteid elements to become changed into fat. He denies the possibility of transforming carbohydrate into fat in the animal economy, although it does take place in the vegetable kingdom. Lawes and Gilbert at the agricultural station at Rothamstead conducted experiments in connection with animals. They took two pigs as nearly identical as possible, killing one to estimate its fat and then feeding the other on proteid and a large proportion of carbohydrate for several weeks, keeping an accurate estimate of the amount of proteid given and then killing to determine the amount of fat The result was that the fat could not be accounted for by the proteid food. Confirmatory experiments have been made by more recent experimenters, confirming the view that carbohydrate is converted into fat. It seems probable that when the carbohydrate is broken up into separate elements a further synthesis should be possible in the formation of fat. The experiments in connection with nitrogenous equilibrium where carbon taken in the food is stored up in the body, the carbon disappearing from the excretions, indicate the transformation of carbon into fat. It has been found that where carbohydrate is used largely in the food the amount of CO_2 excreted is largely increased without any increase in O, the carbohydrate being changed to fat.

The question of the formation of fat from the proteid food elements is also important. Dried proteid consists of about 15 per-cent of N and 50 per-cent of C, urea 46 per-cent of N and 20 per-cent C. The urea therefore contains much less C than the proteid, indicating a remnant which goes to fat formation. Voit placed a dog in a respiration box, feeding it entirely on proteid (lean meat),carefully estimating the amount of income and expenditure from the ingesta and excreta with the result that carbon disappearing from the excreta is presumed to be stored in the body as fat, the fat produced being too large to be accounted for by the carbohydrate or fat in the food. In the case of a dog in N equilibrium fed 2,000 grams of lean meat, representing 68 grams of N and 250 of C, the excretions of urine, faeces and respiration 68 grams of N and 207 of C, the C in excess being 43 grams representing 58 grams of fat. This is a direct proof of proteid conversion to fat. In connection with the mammary secretion it is found that pure proteid produces a milk very rich in fat. So far is this carried that it has been stated that the milk becomes more rich in fat the larger the amount of proteid in the food. In the process of cheese ripening it has been found that the amount of proteid decreases while the fat gradually increases. In the case of a fasting dog to which phosphorus has been given it has been found that 40 percent of fat is in the muscles and 30 percent in the liver as against 16 percent in the muscles and 10 percent in the liver of normal dogs. The phosphorus produces fatty degeneration of the tissues. The administration of phloridizin aids in proteid disintegration and the fat accumulation in the liver cells. There is also an increase in nitrogenous excretions indicating an increased metabolic action the CO_2 being decreased. This seems to

indicate the change of proteid to fat. Voit carried this idea so far as to maintain that the carbohydrate acted in connection with fat formation only in sparing the proteid oxidation and thus permitting a large proportion of proteid to become transformed to fat. He said that the proteid particle becomes dissolved, the nitrogenous element being removed C, O and H remaining in the proportion sufficient to form fat. Rubner in line with this estimated that 46 per-cent of proteid could be transformed to fat. He found that in a dog fed upon a rich carbohydrate diet with little fat and no proteid the deficiency of C was greater than could be accounted for by proteid dissolution in the body and the fat of the food, the result being that fat was formed from carbohydrate. This extreme view has been abandoned even by Voit who admits the formation of fat from carbohydrates. The true conclusion seems to be that both proteids and carbohydrates are necessary in the fat formation. The proteid necessary is not very much in excess of the amount of proteid loss in connection with the tissues. As the carbohydrates go in the metabolic processes to the production of energy and heat,if the proteid is too small there will be little carbohydrate for fat formation. Pfluger as we have seen denies the possibility of fat formation from proteid, explaining the case of feeding a dog on lean meat by the fact that in the meat there was sufficient fat to account for the fat formation, the exclusive source of fat being the fats and carbohydrates. Pfluger admits that in certain bioplasmic forms there is fat formation from proteids but that only under the influence of germs or bacteria or enzymes of some kind. That this is untrue has been shown from the fact that meat if kept in a solution of milk of lime will lose part of its proteid substance in the formation of fatty acids. In the case of the administration of phosphorus to starving animals, fatty cell degeneration takes place in the tissues, indicating fat formation in connection with proteid tissue. It is evident that there is a fat formation in the body. When there are found in the food foreign fats these are not found in the body fats or only to a small extent; a change taking place by which vegetable or animal fat becomes assimilated to the particular animal fat. This indicates the power of fat formation in connection with the fat cells of the adipose tissue.

The question arises, has the liver anything to do with fat formation? Microscopic examination of the hepatic cells of any of the domestic animals, particularly if they are deprived of freedom, indicates the presence of fat globules in large numbers. Pavy claims that in the liver the glycogen becomes transformed directly to fat. Paton contends that the opposite is the case,although in the experiments made by him there is an increase in the fatty acids of the liver when the glycogen is disappearing, about one-half of these fatty acids combining with lecithin. In connection with the outer parts of the hepatic cells of frogs Langley found fat accumulating, during the winter season when the glycogen is also accumulating, both of these disappearing gradually under the influence of artificial or natural warmth. In cases of fatty liver the hepatic cells are filled with fat. These experiments may simply indicate the fact of the storage of fat in the liver. The fat formation seems to be connected in some way with glycogen formation. It is probable that the fat is stored in the liver for further transformation into the body fat of the specific character found in the animal itself; it has been found that liver fat has less olein than the body fat and is more difficult to liquidize, has more of the fatty acids—these facts indicate that the fat is stored in the liver for metabolic processes.

If the fat is removed as rapidly as its formation takes place it may be oxidized or become part of the adipose tissue. When the removal is interfered with abnormally the liver cells become filled resulting in an increase of the organ, indicating that any interference with respiration or oxidation interferes with fat removal. This is in line with the fact that where respiration is very active as in birds the liver is very small, whereas in cases where respiration is less active as in fishes and embryonic stages the liver is large. It is claimed that in the case of persons residing in the tropics the liver becomes enlarged if the diet is over-rich in fat forming substances.

Mammary Gland Metabolism.—We examined the mammary gland secretion in connection with the secretion proper and yet there are certain facts associated with milk secretion that belong to the field of metabolism. The gland when resting is not so large as the active secreting gland, the alveoli being less numerous and also smaller in size. Each of these alveoli consists of a number of small cells. If the mammary secretion is not excited by the pregnant condition of the uterus these cells grow very slowly, the metabolism being slight and the metabolic products passing into the blood do not accumulate in the gland. When pregnancy takes place the gland develops chiefly in connection with the formation of new alveoli. When the parturition period approaches there are metabolic changes in connection with the central alveolar cells, chiefly in relation to fat transformations, these central cells being destroyed, a single layer of cells remaining that line the alveoli and carry on the secretory processes. These broken up cells are found in the colostrum. After this colostral fluid has passed off the normal milk is secreted. The milk consists of (1) proteids, casein and lactalbumin; (2) the fats, olein, stearin and palmitin with the glycerine compounds, lecithin, cholesterin and the pigment; (3) lactose which by fermentation becomes lactic acid, the ferments being found in the milk even in the gland; (4) the salts, especially calcic phosphate, potassic chloride and sodic chloride, thus resembling the body tissue in the inorganic constituents.

In the case of the milk secretion there are definite morphological changes in the cells. When the empty gland begins to fill up with the secretion the cells are found to grow, as the cell substance increases, being elongated into the alveolar lumen. This is followed by the division of nucleus, the two nuclei becoming embedded in the cell substance while the milk substance becomes secreted. This is followed by the expulsion of the material, accompanied by the cell division, into the alveolar lumen. The nuclein arises from the divided nuclei, the cell substance forming a part of the milk secreted, the water and salts being secreted in the ordinary way. In this we find the evidence that secretion, at least in the case of milk, involves a metabolic process. By the cell activity the blood yields the milk, the transformation taking place within the cells. By the use of proteid food the fat in milk is increased, the proteid increasing metabolism and in this metabolism providing fat; on the other hand the use of fat in food diminishes the fat in milk, lessening the metabolic activity. The fat formation in the case of dieting on proteids takes place in the cell. Even the formation of casein is due to cell activity. The presence of albumin in a semi-peptone condition indicates that proteid metabolism takes place in the cells. The lactose which is found only in the mammary gland cells is formed in the cell, supposed to be derived from a semi-glycogen found in the mammary cells. There is thus in the mammary gland cell evi-

dence of the metabolism in connection with the proteids, carbohydrate and fats. This proves the direct relation of the mammary secretion to metabolic activity.

SECTION VIII. The Effect of Muscular Activity, Exercise and Massage.

That the metabolism of the body is affected by exercise, sleep, temperature, etc., is almost presumed. Metabolism takes place largely in the muscles. There is a certain amount of muscle metabolism constantly going on both in activity and rest. It is much larger during activity. This is evident from the fact that there is a much larger amount of CO_2 given off during activity from the body. There are more chemical changes taking place in the muscles during contraction, resulting in the production of sarcolactic acid and CO_2 and using up glycogen. The exercise of the muscles increases the amount of food used and, therefore, the metabolism. There is considerable difference of opinion as to the effect of this metabolism. Liebig holds that the energy of muscular exercise originates from proteid metabolism, so that when the muscular exercise increases there is a corresponding increase in proteid metabolism and in the nitrogenous excreta. The refutation of this theory has been based upon a number of experiments in which it was found that proteid metabolism does not furnish all the energy of body exercise. Fick and Wislicenus ascended the Swiss Alps, estimating the amount of work done in the ascent in connection with their body weight, the heart action and the muscle activity. For almost a day before ascending, during the ascent which occupied eight hours and for six hours after the ascent they ate only non-nitrogenous food. The urea, which must have originated from the body proteid did not represent an energy equal to the work done, proving that the energy of the work and exercise did not all arise from proteid food. Voit made experiments upon man and also upon dogs the results of which indicate that under ordinary circumstances muscular exercise does not affect the amount of proteid metabolized, there being no well marked increase in the urea excreted during exercise. This seems to lead to the opposite theory to that of Liebig, namely, that the oxidation taking place in connection with exercise is really in the non-proteids. Some recent experiments under Pfluger in which the nitrogenous excretion in connection with the faeces, urine and sweat was carefully estimated, seem to indicate an increase in the nitrogenous excreta, indicating increased proteid metabolism. The diet in this case, however, was largely proteid, the non-proteid being small. This indicates the fact that in case of a large proportion of proteid and a small proportion of non-proteid food the proteid metabolism is increased during exercise.

Another element to be estimated in connection with muscular energy is the CO_2 eliminated. During exercise there is a large increase in CO_2. Experiments have proven that comparing rest and work the amount of CO_2 in the latter case is twice that of the former. This is additional confirmation of the idea that the energy in connection with muscular work springs largely from the metabolism of non-proteids. The muscle is proteid but the activity of exercise does not increase the proteid metabolism, the chemical changes depending upon the non-proteids. Muscular activity implies the using up of glycogen in connection with the muscles. That this is so is proved by the fact that when an animal is deprived of

food, the glycogen is used up much more rapidly if, while fasting, it is made to work. In addition to this it has been found that when a muscle has been subjected to prolonged contraction more saccharine matter is extracted from the blood by the muscle; if there is abundance of sugar to supply the muscle, the fatigued condition is diminished and the capacity for work is increased. So long then as the glycogen or sugar remains the muscle draws upon these but when these become exhausted fats and proteids are drawn upon to supply matter for the metabolism associated with exercise. The inactivity of muscle, as for example during sleep, does not affect the proteid metabolism but does affect the non-proteid, the nitrogenous excreta being preserved and the CO_2 excretion diminished. Less material is required to maintain muscular tonicity and the contraction being less there are fewer metabolic changes. A change of temperature external to the body affects the metabolism, a fall in external temperature increasing the metabolism of non-proteid, a rise in temperature decreasing the non-proteid metabolism, resulting in the former case in increased O consumption and CO_2 excretion and in the latter case in decreased O consumption and CO_2 excretion. This arises chiefly in connection with the stimulation by reflex action of the motor nerve to the muscles, the sensory temperature cutaneous nerves being stimulated by the changes of temperature. This is an additional proof of the effect of muscular activity, the muscle metabolism being increased in connection with the non-proteids.

Although it is well known that CO_2 is eliminated from the body as a result of muscular exercise, yet it is not definitely known that this is formed in connection with the muscles. Experiments have been made in connection with the removal of the muscle of a frog, subjected to tetanus compared with the muscle at rest, in regard to CO_2 and also by calculating the amount of CO_2 in the venous blood of muscles in the case of animals during contraction and rest of the muscles. Contradictory results have been found, namely, in some cases it is found that the CO_2 eliminated from resting and tetanized muscle is about the same, and in other cases more has been found during tetanization. In 1897 Fletcher presented a communication to the Physiological society in which he gave the results of very delicate experiments in regard to estimating the CO_2. In using the tortoise muscle, both the voluntary and cardiac, he found only a very slight difference between resting and active muscle in CO_2. He concludes that the opposite results in previous experiments resulted from the prolongation of the stimulation, producing rigor mortis during which it is found that CO_2 in largely increased. This may be taken as the most recent result on this point.

By estimating the amount of CO_2 in the blood passed through muscular tissues compared with the blood on entering the muscle contradictory results have been obtained. The more recent experiments on muscle, through which blood or serum has been perfused, indicates that there is an increase of CO_2 during activity of muscle, although the objection of Fletcher holds here also that prolonged excitation of the muscle may induce the rigor mortis condition and this may acount for the amount of CO_2. The question, therefore, remains unsettled whether the CO_2 is produced in the muscle during activity or whether some substances are given off from the muscle, the result of the oxidation elsewhere being CO_2 production. What is the effect of muscle metabolism on the body proteid metabolism? Liebig held the theory that the oxidation of mus-

cular substance produced the energy of muscle contraction. Following from this was the fact that muscular exercise increased the nitrogenous excretions in the urine. This theory was set aside, as we said, by the experiments of Fick and Wislicenus. The result to be drawn from their experiments was that non-proteid material must have furnished the energy. Experiments on dogs and men seem to confirm this view. Zuntz estimates that each kilogrammeter of work in ascending represents a consumption of O thirteen times greater than the amount of O consumed in walking. We found that the CO_2 excreted is increased according to the amount of body exercise. These facts indicate that the oxidation of non-proteid furnishes the energy, although the proteid oxidation assists, but only to a slight extent. There are cases reported in which the amount of nitrogenous excretion is increased but this can be explained from the fact that in case of an excess of work done the metabolism becomes abnormal or the non-proteid of the food may have been insufficient to furnish material for oxidation in the production of energy and heat. The proteid of the food is called upon to furnish matter for oxidation in these circumstances and this accounts for the amount of nitrogen in the urine.

Pfluger however takes these experiments as indications of the truth of the Liebig theory. He has been supported by Argutinsky who has proved by repeating the Fick experiment that the amount of nitrogenous excretion was increased about 20 per-cent during the time of the experiment and the next two succeeding days, the large amount of energy produced being due to proteid oxidation. Even when the carbohydrate was largely increased in the food the nitrogenous excretion continued sufficiently large to account for a proportion of the work. It has been pointed out that in these recent experiments sufficient food on the basis of caloric value was not taken, so much so, that the body proteid was called upon to make up the loss in the production of energy. Hirschfield has pointed out that his experiments lead him to conclude that muscular energy can be produced from proteid oxidation, that where the diet is sufficient the N excretion is not largely increased, but where the diet is insufficient the N excretion is increased, due to the body tissue metabolism. Pfluger holds that in producing energy the bioplasm uses proteid by preference and only non-proteid when the proteid is insufficient. It is generally believed however that the non-proteid is first used up and only after this is the proteid used in the production of energy. It has been pointed out that the diet of athletes is largely proteid. But it must be rembered that proteid diet is not their sole food. The test of working men whose working capacity is much larger than the ordinary athlete indicates their subsistence on a large proportion of non-proteid and not sufficient proteid to sustain their work. Proteid is more assimilable and when assimilated is a more rapid tissue builder, hence it is more commonly used in connection with athletic training. It is certain that in the increase of muscle activity there is an increased CO_2 excretion which can not be accounted for on the basis of nitrogenous excretion, so that it must depend upon non-nitrogenous oxidation. Bernard held that the glycogen of the liver becomes oxidized in connection with the tissues in producing energy and heat. Seegen more recently puts forth the theory that muscular energy arises solely from dextrose oxidation. Dextrose is always present in the blood even when animals are deprived of food and in the hepatic veins the sugar is found in excess, together with the loss of sugar through muscle activity,

represented by the absence of sugar in the venous blood leaving the muscles. These facts seem to indicate that muscular energy is produced at the expense of carbohydrates. Mosso found that muscle could do more voluntary exercise if a large amount of sugar is in the food. Pfluger found that a dog which at rest could be kept upon pure proteid in N equilibrium, when made to exercise lost flesh if kept on the same diet. When reduced to an equilibrium on a lower scale he fed non-proteids, the result being that the animal gained in flesh, putting on fat from which he concluded that the proteid is preferable in tissue building and only when the proteid is insufficient is the non-proteid consumed. Schaefer says that while muscle can only be built up from proteid, it is also true that muscle activity can produce energy out of non-proteids, the oxidation probably taken place outside of the bioplasm, so that with the smallest tissue loss the food elements are used up in oxidation to produce energy. That this is so is evident from the fact that where animals are fed on mixed foods the proteid used up would not account for the oxidation necessary to produce the energy. Energy is always produced much in excess of the work demanded, the amount in excess being transformed to heat. When we add to this the fact that if the muscular exercise becomes severe there is an increased amount of sulphur, phosphoric acid and lime in the urine; the first in sulphate form increasing according to the N increase, the second more than the N increase and the third marking a decomposition of the bony structures of the body. There is no doubt a slight variation in urea with muscular exercise, although the variation is often hidden by the variations in the diet. The experiments of Zuntz prove that if muscular exercise is very severe there is a decomposition of the tissue proteid increasing the urea excreted. It has been found that in the case of the hibernating marmot during hibernation the loss is very small as compared with the loss during activity, indicating that tissue proteid is lost both during hibernation and activity the urea excretion continuing.

While therefore the non-nitrogenous elements furnish in the main the energy of the body there is always a nitrogenous decomposition associated with severe work. In muscular tissue we find a large proportion of globulin the nucleo-proteid being scarce. If we find an increase in the N excreta, accompanied by increased excretion of uric acid and phosphoric acid, this would indicate that the proteid material for metabolism was furnished at least not by the muscle. In the case of starvation one tissue supplies another with matter. This may possibly be the case in muscular exertion. A series of experiments are reported from the laboratory of the Royal College of Physicians, Edinburgh, under the directions of Dunlop and Paton. In order to make them complete the N excretions and also the inorganic excreta were carefuly estimated. Perspiration and the influence of muscular activity on the blood and the lymph flow were also taken account of in connection with the Turkish bath and massage. Five experiments were conducted—three to find out the influence of severe exercise, one the effect of sweating and one of massage. The subjects were dieted very carefully for a week on a constant diet and the muscular work was performed on the fourth day, giving a period before and after for watching the conditions. In regard to the N of the urine it was found that there was a marked increase due to severe muscular exercise, this increase being found after the exercise on the two following days, the increase being estimated from five and one-half to eight grams

representing an N consumption of 180 to 250 grams of flesh In the case of the sweat test it was found that there was not any increase of N in the urine, during the period of observation there being an N deficit below one gram, this loss probably representing N loss in perspiration, Argutinski having estimated a day's exercise as representing a loss of .75 grams of N in sweat. In the massage case there was no perceptible variation in the N excretion, from which it is inferred that the influence of muscle contraction on the flow of lymph does not vary so far as indicated by the N in the urine. In regard to the urea the excretion was increased by exercise, lessened slightly by perspiration and unchanged by massage. In the case of uric acid there was an increase in two experiments and a decrease in one. In the last case the person was in good muscle training, while the other two were not, indicating the cause of increase in uric acid to be found in the muscular training. In the case of ammonia exercise produced a marked increase in the excretion, this representing the acid formation in connection with muscle katabolism, sulphuric acid being formed by the oxidation of proteid and sarcolactic acid by the oxidation of the non-proteids. In the case of the chlorides there was a diminution in connection with exercise and sweating, representing a loss of sodium chloride in the sweat. In the case of the phosphates there was an increase in the massage experiment due to the increase in the flow of lymph which carried off phosphates from the tissues.

In connection with these changes, these conclusions were reached; (1) that there is an increase in the katabolism of proteid in the case of severe muscular exercise, represented by the increased excretion of N and S in the urine; (2) in this katabolism it is muscle proteid that is used up as indicated by the fact that the increased N and S excretions are not associated with increased uric acid and phosphorus excretion, the muscle not being rich in the nucleo-proteids that produce these; (3) in case the person doing severe work is not in proper muscular training the proteid loss is associated with the nucleo-proteid loss represented by the increased uric acid and phosphorus excretion. In the case of massage the increased excretion of H_2O and phosphorus is ascribed to the physical influence of an increase in the lymph flow which bears these substances out of the tissues, so that there is not necessarily any increase in katabolism. This would seem to indicate the importance of muscular training in economizing the body substance, as by such training the muscle is prevented from drawing upon other tissues for proteid thus decreasing the necessity for excessive metabolism and so economizing the body substance.

SECTION IX. Influence of the Ductless Glands on Metabolism.

The influence exerted upon the metabolic processes by different organs of the body is specific. The liver, as we have seen, has an important influence on carbohydrate and proteid metabolism, the pancreas has a mysterious influence on carbohydrate metabolism, while the kidneys have something to do with the prevention of tissue waste. The excision of the testes and the pancreas removes from the body certain materials that influence metabolic processes, especially in connection with carbohydrates, whether the action is direct or indirect through the nervous system. As we saw before, Brown-Sequard and others have claimed that

the extracts of these glands have a tonic effect upon nerve and muscle. Besides these we have what are called the ductless glands, sometimes the blood glands, which give certain substances to the blood necessary to body nutriment. As we saw in speaking of secretion, the substances secreted in these glands form the internal secretions, so called because they are not found in connection with a free surface but are carried through the blood or lymph into the general circulation. These are five in number, the thyroids, the pituitary body, the supra-renal bodies, the thymus and the spleen.

1. The Thyroids.—The thyroids are secreting glands consisting of alveoli lined with epithelial cells which are filled with colloid. The cells exhibit secreting activity. Drechsel thinks there are several substances in the secretion representing different functions. The gland is very vascular and nervous, these elements being closely connected with the cells. It seems to be very active as a gland in youth, becoming degenerated in old age. We have already seen that thyroidectomy, at least in dogs, always results fatally. Disease in the thyroid represents an abnormal condition such as goitre, cretinism and certain myxœdematous hypertrophied or hyperplasiac conditions which are characterized by the large amount of mucin found in the connective tissues, the glands becoming embryonic in this respect. Halliburton has shown that in normal thyroids there is a large amount of mucin. This myxœdematous condition has been identified with the same symptoms as in cases of thyroidectomy, symptoms that indicate nervous disorders in connection with the nutrition of the nervous system. These systems can be avoided by subcutaneous grafting of a part of the glands. Dogs do not exhibit the myxœdema, probably because the death results so speedily as compared with man and monkeys in which there is a swollen condition together with cretinous symptoms and spasms prior to death. In man as he becomes advanced in years, and in birds and herbivora these symptoms are not found, in the latter case said to be on account of the presence of the thyroid accessories. Associated with thyroidectomy we find not only abnormal nervous conditions but also certain metabolic conditions. Leaving aside the nervous changes which are associated with muscular twitching, spasms and tetanus, cretinous conditions, loss of temperature and sensibility, the metabolic changes are associated chiefly with the connective tissue which becomes swollen and filled with a large quantity of mucinoid substance. Accompanying the swollen condition of the integument is a dilated condition of the eyes, the dryness of the skin and the loss of hair. Following the hypertrophied condition is a condition of atrophy. The nerves spring from the pneumogastrics and the cervical symyathetic ganglia. The nervous changes which arise from central origin, at first are associated with a rise of temperature followed by a distinct fall below the normal. The thyroid secretion seems necessary for the nutrition of the nervous system. Semon's theory is that the chemical activity and growth of the connective tissue is cut short so that instead of evolution there is devolution, the connective tissue degenerating back to an embryonic condition characterized by excess of mucin, finally yielding to disintegration.

Two theories have been brought forward to account for this condition. (1) The auto-toxication theory, according to which the glands remove from the blood certain toxic substances rendering the body immune from their noxious influence. If this were true the thyroid would be largely absorbent and excretory. (2) The other theory which is of met-

abolic value regards the thyroids as the source of an internal secretion, this secretion being necessary for the metabolism of the body, especially in connection with the trophic condition of the nervous system and the connective tissue. The truth of this theory seems to be proved by the fact that thyroid injections have a good, not an evil effect, in thyroidectomy and myxœdema conditions. Even in the case of a normal individual thyroid injections, if made in the veins, produce a lowering of blood pressure, an increase of the radial artery caliber, also producing increased body metabolism accompanied by a large increase in the urine excrecretion and a lessening of the fat of the body. In the case of the removal of the thyroid there is certainly a nervous change which is found to result in a change in the respiratory exchange of gases, with abnormal changes in body temperature, this latter condition representing a changed condition in the vaso-motor system. In connection with feeding thyroid it has been found that for a time, at least, there was an increased N excretion with sodium chloride and phosphoric acid increase; according to others an increase in the cardiac pulsations accompanied by glycosuria and an increase in the amount of urea in the urine. It seems to be established that the thyroid secretion has an important metabolic value. The close connection with the nervous system has been established in connection with the vessels that supply blood to the brain, the nerves that enter the thyroid being strong vaso-dilators. It has been found that the stimulation of the thyroid nerves lessens the carotid blood pressure, this stimulation may be made, as Cyon points out, by dividing the vagi, the depressor or the cardiac branches of the recurrent laryngeal nerves and stimulating the cut ends. After thyroidectomy the stimulation of the nerves becomes less sensitive. This has an important osteopathic value, because the great vascularity of the thyroid and its close and delicate nervous connection with the brain and with the heart and other organs through the vagi and depressor nerves makes it a most important structure in osteopathic manipulation.

2. The Pituitary Body.—The anterior portion of the pituitary body situated at the base of the brain is glandular in structure and seems to be analogous in function to the thyroids. It is quite vascular with few nervous connections. In the case of its removal from cats and dogs it results fatally, death taking place inside fourteen days. Associated with the removal of this gland we find loss of temperature, loss of appetite and fatigue, tremors passing into spasms and difficulty in breathing. In some of the symptoms we have the analogy of the thyroids. In case of the thyroid removal it is said that it sometimes results in the substitution of the pituitary gland for the thyroid. On account of the closeness of these two it is inferred that the pituitary furnishes an internal secretion of value to the nervous and muscular tissues. Some claim that in myxoedema there is an enlargement of the pituitary gland so that the thyroid and pituitary are connected in this pathological condition. It is certain that when the pituitary is enlarged there is a hypertrophied condition of the face or extremities, due to the hyper-function of the hypophysis. Associated with this same condition is said to be an abnormal thymus development. Schiff by feeding pituitary extracts found that there was a large increase of phosphoric acid with very little increase in N, indicating that the pituitary has an important influence on the osseous metabolism. The use of pituitary extracts has been found to increase very considerably the heart force without increasing the heart beat, accompanied by a

rise in the blood pressure, this latter result being due to contraction of the arterial capillaries. Experiments have been made to prove that this effect is direct and not through the nervous system. By cutting off all nervous connection in the case of a frog and injecting through the circulation a sodium solution with pituitary extracts, the contraction of the blood vessels takes place. This indicates that there passes from this gland an internal secretion which passes directly to the blood, producing heart and arterial contraction while at the same time influencing the metabolism of bone and nervous tissue.

3. THE SUPRA-RENAL CAPSULES.—These are intimately connected with certain nutritive processes. In the case of Addison's disease which is tubercular in its character and seems to be localized in the medullary part, associated with loss of strength and the characteristic bronzed skin and membranes we find a pathological condition of these bodies. It has been found that the excision of these bodies results fatally in a short time, from one to three days, whereas if only one is removed no abnormal results are noticeable, the abnormal conditions resulting from removal being similar to those found in Addison's disease. The vascular system loses tone, death being produced by paralysis of the respiratory muscles. The vascular system seems to be affected, as some toxic substances in the blood have a marked effect when injected into other animals that have recently been deprived of these supra-renals, although no effect in the case of normal animals. In the case of injected blood we find the symptoms of poisoning associated with the paralysis of the muscles and nerves indicating the accumulation in the blood of the muscles of certain noxious substances arising from muscular metabolism. On this theory the function of the glands is to remove from the blood this toxic substance. This is based on the theory of the toxic effect of injected blood, but this does not take account of the fact that in case of any animal dying gradually its blood would have a toxic influence. Aside from this negative function of these bodies it is certain that there is produced in connection with these bodies an internal secretion which has important properties that it brings to the blood. It has been found that the injection subcutaneously of extracts of the supra-renals in large doses increases the heart beat, quickening respiration and producing a fall in body temperature. In the case of some animals like the rabbit large injections produce rapid death. By injecting the extract into frogs in connection with the lymph there is found paralysis, the back part of the body, especially the limbs, becoming paralyzed before the front part. When injected into the blood there is a strong effect noticed in connection with he muscles, especially the cardiac muscles and the arterial walls, upon the nerve centers in the medulla, chiefly the cardio-inhibitory and respiratory centers. In the case of the ordinary muscles muscular contraction becomes prolonged. In the case of the heart if the pneumogastrics are intact the injection of the extract slows and in some cases arrests the auricular contractions, the ventricular beating continues slowly and the pulse being also slowed. If the pneumogastrics are divided the auricular and ventricular contractions are increased, driving out a large quantity of blood into the arteries, raising the arterial pressure very considerably. In the case of the arteries there is contraction of the capillaries, the contraction resulting directly from the effect of the injected substance upon the muscular substance in which the arteries are found. Even if the spinal cord is divided or the medulla removed the same effect is noticeable, so that it must b

due to direct action and not through the nervous system. In the case of the rise of blood pressure when the pneumogastrics are divided the pressure may be raised to five or six times its normal, this being produced by direct action on the capillary arteries. These results in the case of injection into the blood of the veins do not last long, the vessels becoming normal very quickly and the action of the heart also gradually becoming normal. In case of the effects upon the vascular system it is possible to stimulate the action of the blood vessels through the depressor nerve in connection with the vaso-motor center and yet very quickly the effect ceases, probably because the nocuous substances become stored in some organ or organs possibly the muscles. In the muscles the effects are noticeable for the longest time. The substance seems to be associated with the medullary parts of the capsules and is very powerful .0055grams of the supra-renal when dried being sufficient to get the greatest effect on the heart of a dog. The medulla is entirely different from the cortex, the former representing the sympathetic ganglia. There is a rich blood supply indicating that active metabolism takes place in connection with the bodies, in the pigment provision. There is also an abundant nerve supply indicating close nervous connections. The medullary part is whitish as distinguished from the cortical part which is yellowish and also very subject to become decomposed. As the medullary part is only a small part of the capsule and as it is largely proteid in composition there is only a very small part left that is subject to the chemical action, so that the actic part of the gland is very small. This would make the active substance very powerful in action, one millionth part of a gram per kilogram of body weight being sufficient to produce an effect on the heart and arteries. It may be concluded that there is being continuously secreted an internal secretion which when passed to the blood has a very powerful effect in connection with muscular metabolism, particularly the muscles associated with the vascular system. The substances formed pass into the blood and when brought to the muscles exercise a beneficial influence upon muscle contraction, particularly cardiac muscle and the muscular walls of the arteries, so that the secretion has an important metabolic function.

4. The Thymus.—This like the medullary part of the supra-renals is lymphatic and by some is considered part of the lymphatic system. Unlike the other glands the blood vessels although abundant are small and hence the thymus is not vascular. In connection with the thymus there is extracted by the use of a sodium solution a nucleo-proteid which contains about .8 per-cent of phosphorus and is said to have some relation to fibrin formation. So much is this so that if the thymus extract is injected into the blood there is produced an intravascular blood coagulation. In addition to this nucleo-proteid there are found in connection with the gland xanthin, hypo-xanthin, leucin and lactic acid. As it is more fully developed in embryonic life and disappears gradually after birth it is supposed to be connected with the metabolic functions of developing tissue.

5. The Spleen.—This organ on account of its size and the largeness of its blood supply as well as its close relation to the organs of alimentation has important nutritive functions. And yet the spleen can be entirely removed both in animals and man without any serious disadvantage to the system or resulting fatally. It has been found, in certain cases at least, on the removal of the spleen that the animal developed an abnormal appetite with an increase of body flesh but these are not invariable. It is

presumed that on the removal of this organ the functions are discharged by some other organ such as the lymphatic glands. Schaefer reports that in a case in which he removed the spleen he found an increase in the lymphatic glands which are related to the blood. As the function of the spleen is supposed to be connected with the formation of the lymph corpuscles and the red blood corpuscles, this function would seem to be capable of performance by other organs rich in lymphoid tissues. There is in the spleen a special function associated with the disintegration of the blood corpuscles as a large amount of iron together with haemoglobin are found in the spleen in different stages of transformation. The spleen is supposed to disintegrate some of the red blood corpuscles the pigment being sent to the liver either in the haemoglobin form or in the bile pigment form, neither of which are found in connection with the blood of the splenic vein. Others ascribe to the spleen the function of forming new red blood corpuscles, as the leucocytes, such as are found in the red marrow of bones are often found in the spleen and in the case of extensive bleeding these are found especially in the spleen.

Schæfer thinks that the chief function of the spleen is to act as a storehouse in which the portal blood is deposited, in other words, to receive the blood when there is a tendency to over-much blood in the viscera. In proof of this he cites the rhythmic action of the spleen in contraction and dilatation which seems to indicate that the spleen aids the flow of the portal blood sending it on to the liver, in this way preparing the blood for the important metabolic changes that take place in the liver. In connection with the spleen we find the delicate arteries opening into the recticulum, so that the blood passes freely between the reticular cells. In this way there is a large volume of blood freely flowing through the meshes of the spleen pulp, the amount varying in different conditions of the organ. The spleen changes its size, after a meal becoming larger and continuing to increase during several hours. Pathologically such an enlargement is found in ague; when the ague becomes chronic the spleen becomes permanently enlarged. This enlargement arises from the dilatation of the arteries associated with the local inhibition of the contraction usually found in the muscle fibres. The normal tonic contition of the spleen depends upon the regulation of the central nervous system. By tracing the spleen curve in connection with the plethysmograph we find that the movements accompany the respiratory movements not the heart variation, that is, do not depend upon the blood pressure. They seem to depend upon the amount of blood retained in the spleen and not so much on the increase or decrease of the flow through the spleen. The contractions and relaxations are undoubtedly due to contractions and relaxations of the muscle fibres, in other words, the muscular contraction and dilatation represent the accommodation of the organ to a decreased or increased flow of blood. This muscular contraction is subject to nervous control. The stimulation of the vagus produces a rapid contraction of the spleen directly; reflexly such a result follows the stimulation of the central end of any sensory nerve. By the excitation of the medulla through a galvanic current the same result may be gained. Thus, the nervous sysem regulates the blood flow through the spleen, the blood undergoing certain metabolic changes in its passage.

As we saw, the spleen transformation has an important influence on the liver changes, because the changes in the spleen and the amount of blood passing through it must influence the liver action. In the spleen

we find a special substance of proteid nature, alkaline in character and combined with iron. This iron proteid, together with pigments, which are associated with C., seems to have an important bearing on the hæmoglobin changes. In the spleen we find only a very small proportion of potassium and chloride with a large quantity of phosphate and sodium, being very abundantly supplied with extractive substances such as butyric, lactic and formic acids, with leucin, xanthin and uric acid. It is peculiar that uric acid is formed in the spleen of all animals, even in case of the herbivora whose urine does not exhibit any uric acid. These substances especially uric acid and leucin indicate the metabolic activity of spleen.

6. THE KIDNEY, PANCREAS AND LIVER.—As we have been discussing the internal secretions it is important to notice the distinction of the external and internal secretions in the liver and the importance of this secretion in connection with metabolism. All that we know at present is that certain substances carried to the liver after being changed are excreted as bile, others are taken up by the liver cells, changed, stored for a time in the cells and given out again to the blood. The bile is regarded as an external secretion of the liver while glycogen is an internal secretion. In one sense all the body tissues are engaged in forming internal secretions because when substances are absorbed from the blood and lymph they are given out again, except so far as transformation takes place in the upbuilding of the tissues and in excreting substances in connection with certain ducts. The internal secretion of the liver is more important than the external. If the liver is removed the animal can not survive but it can survive even if by the opening of a fistula the bile is permitted to escape continuously. If the pancreas is extirpated death results in many animals and in the human subject there is a diabetic condition induced which results fatally. If however the pancreatic juice is lost by means of a fistulous opening life is not impaired, although the fat digestion and absorption is weakened. The removal of the kidneys also results fatally. Death seems to result from the interference with certain necessary metaboblic changes, in the case of the pancreas resulting in sugar accumulation and in case of the kidneys in urea accumulation in the urine. Associated with both of these there is an increased proteid decomposition. Evidently the kidney and pancreas have an important metabolic function in connection with the fluids of the body like the liver, either extracting from them or sending out to them certain substances that are of great importance in connection with metabolism. According to Schaefer the pancreas is concerned in the formation of an internal secretion which is found in the peculiar part of the gland forming the epithelioid tissue. That these organs have an important metabolic action seems to be proved but as yet we can not definitely state what it it.

When the liver is removed in the frog and in birds there is the absence of the bile acids and pigments from the blood. These substances therefore must be formed in the liver and not simply separated from the blood. If haemoglobin separated from the blood corpuscles is injected into the circulating blood, the bile pigment is found in the urine. If this is done by injecting a haemoglobin solution or blood rendered laky by the thawing and freezing process, the bile pigment is increased to such an extent that it does not all pass to the bile duct but is in part thrown off into the blood and then into the urine. This indicates that the bile pigment, bilirubin, is simply transformed hæmoglobin, the proteid and iron elements being removed.

a fact which is proved by the presence in these cells of certain combinations of iron and proteid. Even when the liver is thoroughly washed out there is found in the hepatic substance some iron varying in quantity. The iron is in combination with some organic substance as it requires to be treated with hydrochloric acid before it will give the sulphocyanide reaction. The bile contains a quantity of iron liberated from haemogoblin but this does not account for all the iron set free, evidently a part goes into a combination with some proteid or nuclein substances. The liver cells therefore have the power of dividing up the haemoglobin part of the split up iron combining with an organic substance the balance being added to the bile. So far as known the hepatic cell acts in the transformation of the liberated haemoglobin into bilirubin, whether the liberation of the haemoglobin from the red corpuscles takes place in connection with the liver cells is not known.

We have found that the red corpuscles undergo transformation to a certain extent in the spleen so that it is inferred by some that one of the splenic functions is to liberate haemoglobin from the corpuscles and to send it through the splenic and portal veins to the liver. That this is not the only origin is proved by the fact that the bile secretion continues after the extirpation of the spleen, so that other parts or organs of the body must discharge this same function. In the formation of the bile acids in connection with the combination of cholalic acid with glycin and taurin, the glycin and taurin arising in connection with tissue metabolism, the liver cells furnish the cholalic acid and also accomplish the synthesis necessary to the formation of the acids in the bile form. The cholalic acid seems to arise in connection with liver cell metabolism but in what way we do not know. When bile is present in the intestines the hepatic cells are excited to increased activity, this being supposed to be due to the absorption of taurin and glycin, these substances exciting the hepatic metabolism in the formation of the cholalic acid. Where we find a jaundice condition this indicates the excess of the bile pigment in the blood, the skin and urine becoming yellow on account of the presence of the pigment. In nearly all jaundice conditions we find the interference with the bile flow, the bile being reabsorbed in the blood. In some jaundice conditions however there is no interference with the bile flow, as in case of acute yellow atrophy of the liver and in yellow fever, in these cases there being an accumulation of the bile pigment but not of the bile acids. The bile formation is said to be closely connected with the formation of glycogen in the liver. They take place in the same cell and further evidence may bring them into close connection.

SECTION X. The Laws of Nitrogenous Metabolism.

We have already discussed the subject of nitrogenous equilibrium in which case there is an exact balance of the income and expenditure, the nitrogen lost being just equal to the amount taken in the food, the carbon lost being also equal to the amount taken in, or the carbon given off may be more or less than that received, in which case the body will be losing or gaining fat, the proteid tissue remaining the same. Inside the limits of nitrogenous equilibrium which represents the normal condition of the healthy adult, the body uses up its nitrogenous income and no storage takes place for the future. When deprived of food the animal economy This is supposed to take place under the active influence of the liver cells,

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* becomes in reality economical. If, instead of starvation, there is a large proportion of proteid furnished to the body, then there is an excess, in which case there is an N storage representing flesh added to the body. Very soon, however, there is a rearrangement of the economy, the system becoming accommodated to the new standard, the expenditure being increased to keep pace with the income. On considering these changing conditions we infer certain laws or principles in regard to the nitrogenous balance that are of interest from a metabolic standpoint.

1. The supply of nitrogenous food regulates, to a large extent, the nitrogenous consumption, in other words, dietetically and physiologically the SUPPLY REGULATES THE DEMAND. This seems to be a most wonderful law from a physiological standpoint and various theorists have tried to explain it. It is said by some that where a large amount of the proteid is taken there is a splitting up of the proteid in the alimentary canal, leucin and tyrosin being formed, these substances forming the short way to the formation of urea without being associated with the ordinary proteid of the blood or passing through the ordinary organs. In this case there would really be a waste of the income, the excess of proteid being taken out of the normal proteid channel and the metabolism of the organs and tissues being saved to this extent, so that it would represent a saving on the part of the organs of the body in the metabolic processes. It is questionable, however, if this takes place to any large extent in the body and when it does take place it represents only a very small part of the metabolism of proteid. By others it is argued that the excess of proteid becomes oxidized in the blood and lymph without passing through the tissues. This, however, is contrary to the generally accepted theory that oxidation takes place principally in connection with the living cells of the bioplasm and not in the fluids of the body outside of the tissues. It seems then that themetabolism takes place chiefly in connection with the cells of the body tissue.

As to the manner in which this tisue metabolism takes place there is difference of opinion. According to some the metabolism takes place, not in connection with the tissue proteid substance, but the circulating proteid which is normally said to be sufficient to carry on the oxidation processes and so to supply the waste in the tissue proteid. This circulating proteid is supposed to be split up and to be acted upon in such a way as to provide for the necessities of the tissues. In opposition to this it is held by others that the tissue proteid itself becomes broken down, remaining only for a short time in its cellular form, the old cells giving place to new cells, the entire food proteid taking part in this process of tissue upbuilding. In opposition to both of these theories it is claimed that no distinction can be drawn between the circulating and the tissue proteid, that all the circulating proteid really becomes tissue proteid and becomes part of the organized substance, afterwards being subjected to the metabolic processes. When there isa large proteid supply in the form of food then there is also an accompanying increase in the amount of bioplasmic dissolution. The cell substance is not destroyed, at least to the extent of destroying, the cells, the destruction and renewal taking place inconnection with the substance that forms part of the cells. In favor of the second theory it is claimed that in the mammary and sebaceous gland there is a cell disintegration which seems to indicate the metabolic process in general as involving cell destruction as the basis of functional activity. But there is no proof that in any other organs, except possibly the mucous glands, such

cell disintegration takes place nor is there any proof that the cell production is so rapid as to account for this theory. If the experiments made by Munk and others are to be credited, in which they found that a dog after fasting when fed with proteid and carbohydrate consumes less proteid than during starvation then the indication is that all the food requires to be built up into the bioplasm before any definite changes of a metabolic character take place.

2. Associated with this is the second principle that NITROGENOUS METABOLISM DOES NOT DEPEND VERY LARGELY UPON MUSCULAR EXERCISE, the variation in nitrogenous excretion not being great whether the individual is at work or at rest. Liebig held the theory that the proteid alone furnished muscular contraction, the non-proteids being oxidized in heat production. Later experiments have proved that mucsular exercise which is produced by the proteid food does not materially influence the urea excretion. The proteid does not furnish materials sufficient for all the energy of the body and hence a portion must be derived from the non-proteid. In addition to this the large CO_2 production and elimination proves that there is during muscular exercise a large carbonaceous decomposition involving fats and carbohydrates. The Liebig theory, therefore, that proteid foods alone produce functional and body energy has been given up. The other extreme has been accepted by some, according to which, proteids are denied any share in energy representing muscular activity, the proteids simply repairing the waste of the muscle, whereas the non-proteid provide the coals of life. This would make the dead substance of the non-proteid furnish the energy of the living bioplasm.

Neither one of these theories seems to be proved by the facts and experiments adduced in support of them. The N excretion does not vary much with muscular exercise, but this does not prove that the energy does not rise from proteid consumption; and the fact that the proteids are not sufficient to provide the energy required in muscular exercise does not prove that it normally comes from the non-proteid. Pfluger has shown that work that is severe both in man and in dogs does produce a change in the N excretion. Even if this were unproved, it would not prove that the energy does not rise from the proteid metabolism. The mechanism of the animal body is such that adaptation is one of the principles of its development. It has a power of accommodating itself to conditions so that if fats and carbohydrates are proteid protectors and savers, when the proteid food is limited, in the same way when a severe drain is made upon the system in severe muscular exercise the proteid may be saved from other purposes of the animal economy to devote it to this especial purpose. This would preserve the nitrogen balance, the proteid being saved from one function to discharge another, when the demand is made upon it. Here the law of demand and supply would also be applicable. Experiments by Pfluger have also proved that where animals are fed largely upon pure proteid there is a capacity for work that can not be explained on the assumption of a small quantity of fat from carbohydrate being found in the food, the energy in this case being derived from the nitrogenous food. In line with this is the fact that the minimum of proteid necessary to sustain normal life is higher where the life is active than where no work is performed. This however does not prove either opposing theory, because in the case of a man who performs hard work there is a larger mass of muscle to feed and consequently the waste will be greater. It would seem then that in the preservation of the N

balance the preservation the of nitrogenous balance does not depend largely upon muscular exercise, this being explained on the basis of body adaptation to varying conditions.

3. Zuntz has made experiments that indicate this additional fact that if muscular exercise becomes very severe and excessive, in other words if it results in dyspnœa there is an increased urea excretion and this results from the dissolution of tissue proteid. In the case of the hibernating marmot there is urea excretion during hibernation, this being due to tissue proteid dissolution indicating the loss of body weight, DuBois estimating the loss at 20 per cent for 160 days of hibernation. If an organ or limb is used excessively it becomes hypertrophied, if it is used less than normal it is atrophied, the former representing hyperfunction and hypernutrition and the latter loss of function and deficient nutrition. A portion of the body that is used more than other parts secures more nutriment, the vessels become dilated and there is an increased blood flow demanded by the tissue necessities. When a part is less used it receives less food, the vessels contract and there is a lessened blood flow. If in the case of a young rabbit the cervical sympathetic is divided the vessels of the ear become dilated and with the increased blood flow there is an increased nutrition of the part so that one ear becomes larger than the other. The same thing is true of any limb or organ, the third law being expressed, MORE EXERCISE, MORE FOOD, MORE TISSUE, the converse being also true. This applies to the particular organs of the body. Physiologically this is illustrated in hypertrophied conditions of the heart and in the intestines and in the difference between those employed in manual labor and those engaged in sedentary occupations.

CHAPTER VIII. NUTRITION PROPER

SECTION I. Introductory.

We have seen in discussing metabolism that it is impossible to describe accurately the metabolic phenomena, representing the many changes through which the food elements pass in the body before being eliminated as waste products. Nutrition follows metabolism because it refers to what takes place in connection with the metabolized food in the nourishment of the tissues of the body. When the food becomes metabolized in connection with the tissues it is assimilated to the tissues. Nutrition takes account of the provision made to compensate for the loss of tissue and fluid in the body. All the body functions we have so far considered tend in the direction of nutrition. Nutrition represents different forms of the process, because in the highly organized portions like the brain or the muscles and in the less organized like the cartilages the process varies. The blood carries with it all that goes to form tissue or secretion, either in the form required as in inorganic substances, or in a form capable of transformation preliminary to assimilation as in the organic substances. All or almost all the tissues are constantly undergoing a process of disassimilation, some parts becoming dissociated and broken down, forming waste matter, and other portions being desquamated like the skin. To sustain life these nutritive processes are necessary and only where life is found do we find these nutritive actions. Life from the standpoint of origin physiologically seems to be the property or principle associated with a certain germinal substance of appropriating matter

from without, the germ gradually appropriating matter untill it becomes completely organized with definite form and size. When life becomes perfected in organism, structure and function, the vital property enables the organism to assimilate new substances so as to regenerate itself. In this living process nutrition begins with the introduction of matter during alimentation. After passing through certain changes the process is continued by the assimilation of this matter to the organism which represents the culminating point of metabolism. Metabolism as first used by Schwann referred to the change taking place in a substance or substances resulting from contact with living cells. Metabolism as used in its wide sense refers to the action of cells whether in the production of the elements of a secretion or in reference to the changes involved in assimilating and disassimilating. The metabolized food elements become part of the living bioplasm and this represents nutrition proper.

The method that is to be regarded as belonging to nutrition proper. as distinguished from metabolism, is the statistical method. By this method the ingesta and excreta of the body may be calculated and compared during a given time so as to lead to certain conclusions in regard to the nutritive value of the food and its assimilation to the body. This method must be received and used cautiously as there is danger of making the matter simply a computation without regarding the living activity of the tissues and organs. In this way the method is open to danger so that care must be taken to use this method simply as a means of suggesting principles that may be confirmed in other ways.

NUTRITIVE CONDITIONS OF THE BODY.—In order to the proper nutrition of the body in connection with metabolism, three things are necessary. (1) HEALTHY BLOOD AND ITS PROPER DISTRIBUTION. If the circulation of the blood is stopped in a limb. organ or other part of the body, thatpart of the body becomes enfeebled, unless a collateral circulationis established to supply it with blood. If the blood supply is quickly cut off the limb or organ becomes mortified while there is sufficient serous exudation; if the supply of blood is cut off gradually the exudation ceases and the limb becomes dry as in the case of the senile gangrene of the extremities in aged people. In order to prevent these pathological conditions the proper nourishment of the body must take place, because only in this way can the blood be kept in a normal healthy condition. In the case of poisoned blood the system makes the effort to free itself from the toxin. In the case of fevers there is always an effort on the part of the excretory system to free the blood from these noxious elements through the skin or the urine. This is found at critical stages in disease in the form of sweating, diarrhœa, bleeding together with certain urinary deposits. This fact is plainly evident in what are called the changes of life in which the change of a single organ affects the entire bodily system, changing the form of the body and giving the body the characteristic features which mark off the adult period of life from the youth period. This indicates the attempt of the body to correlate all its parts in the adult condition. These changes are sometimes spoken of as complemental nutrition. the nutrition of all the parts of the body being complementary to each other. So marked is this nutritive influence that the bodily nutrition may be entirely altered. Thus, under the influence of a vaccine virus or certain eruptive products, as in smallpox, the character of certain tissues may be so altered as to produce immunity from the toxic influences of a certain

virus. This condition, however, is limited by time, because the organ or tissue so altered tends to return gradually to its original condition after a time. This forms a basis for the necessity of revaccination as a means of rendering the system immune against the action of virus. This same process goes on in the bodily system as a whole. There is a constant molecular change according to which the atoms of the body are being renewed and destroyed alternately so that one particle after another is removed to be replaced by new particles. The form is never changed although there is a constant chaos of particles, one particle after another being removed and fresh particles taking their place. In this way the tissues and organs of the body are constantly changing but the charge is a slow and gradual one.

2. Healthy Tissue and Its Proper Nourishment.—This means that the tissue must be prevented from falling into a morbid condition and this represents the border line between Physiology and Pathology. If certain changes are introduced into the nutritive process either suspending certain necessary changes or producing new changes destructive of the tissue then an unhealthy condition ensues. Even however in pathological conditions there is a tendancy to return to the normal condition. This forms the basis of the Osteopathic idea that nature is sufficient to restore the healthful condition if the active metabolism of the body is rendered efficient, the body itself being nature's storehouse of energy and restorative capacity. It is on this basis that Osteopathic manipulation in connection with the circulation of the blood, and especially the formation and circulation of the lymph, becomes most important, because these perform the double function of carrying off all noxious substances and inducing a healthy growth by carrying to the tissues health and life-giving materials.

3. Healthy Nervous Activity.—We have already seen the close relation of the nervous system to the tissues and organs of the body. If a motor nerve is divided the muscle supplied by it will degenerate. If a nerve supplying a blood vessel or a mucous membrane be divided then the result is the degeneration of the affected part. In the case of paralysis the extremities waste unless there is some means of restoring the stimulation supplied by the nervous connection. Thus the entire bodily system depends upon the healthful nervous stimulation, representing the trophic influence of the nerves, the nerve centers and the general nervous system. Psychic influences are most important from this standpoint. The mental conditions affect almost all if not all the organs of the body. The emotions affect body nutrition, for example joy and sorrow have an important influence upon the nutritive processes. Nutrition is promoted by an easy and contented disposition and retarded by melancholic or anxious moods. The same thing is true of diseases and recovery from diseased conditions, the mind exercising either a depressing or an elevating influence upon the diseased organ or the abnormal and impaired function.

Closely connected with nutrition and the nutritive changes is growth. This is manifested either in the development of certain organs or of the body as a whole. If the organ is unduly increased in size it is said to be hypertrophied; if the growth is suspended and the part is wasted from lack of nutrition it is said to be atrophied. In the case of the entire bodily system if the anabolism exceeds the katabolism we have the condition represented by growing youth, whereas in the reverse case we have the senile

stage. In the case of normal growth we may find either the development of existing but hitherto undeveloped tissues or organs or the continuous increase of tissues or organs in active development. These two conditions represent the continuous development of the bodily organs and tissues as well as the development of special organs like the organs of reproduction. All the influences we have already mentioned assist in this development. Functional activity in the case of muscles causes them to grow larger and stronger, the fibers increasing in size and new fibers being developed. Exercise also causes muscular growth. Some muscles are developed without exercise, as the respiratory muscles in foetal life, the germinal muscle energy under the influence of the nerves producing the development. The fact that an increased blood flow is determined to the muscle does not necessarily produce such development, for it requires the muscle contraction to stimulate the bioplasm to take up the nutritive matter. This development however reaches a limit beyond which increased growth is impossible. Sometimes the development is very rapid as in the case of the uterine walls during gestation, representing an enlargement from 25 to 50 times the original size before pregnancy. When muscle is divided and the ends are brought together the junction takes place by nuclei proliferation and the development of new cells. If the divided parts are not brought together the healing process will take place by the development of connective tissue. From what has been said the growth and development of the tissue is promoted ,(1) by active exercise within certain limits which mark the possible enlargement of the tissues; (2) by an increased flow of blood bearing nutrition to the tissues. This requires to be accompanied by muscular contraction to promote the metabolism of the tissues in order that all the nutritive elements may be utilized. (3) These other conditions are only possible in connection with a vigorous and intact nerve connection the muscular contraction and the blood supply being determined by the nerve connection. These represent the conditions of growth in the nutritive process.

SECTION II. The Income and Expenditure of The Body.

The food used in the process of nutrition consists of combinations of simple chemical elements which are altered in the various nutritive processes in order to be assimilated to the tissues. It is necessary to understand body composition so far as the tissues are concerned in their relative proportions and also the approximate elements in the body. Taking a normal adult the percentage proportion of tissue is approximately, muscles 41.8 per cent, fat 18.2, skeleton 15.9, abdominal viscera 7.2, skin 6.9, brain 1.9, thoracic viscera 1.7, other organs and tissues 6.4. The skeletal muscles according to this represent almost one half of the body weight. In these muscles about one fourth of the blood of the body is contained and the metabolism of the body is carried on to a large extent in them. The liver represents the organ next in importance from a metabolic standpoint as it contains almost one fourth of the blood supply and represents a large part of the metabolism of the body. In regard to the substances composing the body structure the following is an approximate estimate. In the case of an adult of 148 lbs we find O 64.43 per cent, H 9.86, C 21.35, N 3.10, Ca 1.89, P .94, S .16, Cl .08, Na .08, Fe .013, K .23, Mg .026, F .013. All of these arise from the food except O which is derived from respiration. The prominent elements in force

production and tissue building are the C, H, O and N, the last being chiefly associated with tisssue formation. In tissue formation also we find Cl, S, P, Fe, Na, K, Ca, and Mg. These are found in different combinations in the body tissues and require to be provided in the food. To determine the proper supply for the body in normal conditions it is necessary to determine the nutritive value of the food elements in the production of energy and in tissue building. Parkes has given the following statistical rules to estimate the chemical elements in the different food materials, (1) To get the N in proteid divide the amount of food by 6.3. (2) To get the C in fat multiply by .79. (3) To get the C in carbohydrates multiply by .444. (4) To get the C in proteid multiply by .535. On this basic table it is easy to estimate the different substances found in the food.

The excretions represent the output and by estimating the distribution of the waste elements the character of the transformation taking place can be reckoned both in the food and in the body itself under the influence of the food. The income must not be taken from the food taken into the system. The faeces must be deducted as they represent largely undigested food, the amount of waste discharged from the blood through the faeces being very small. The income of the body will consist of the various substances found in the food less the faecal discharge. In the expenditure of the body we reckon, (1) The urine excretion representing the N and also a large proportion of water and salts; (2) Skin excretion in conection with the sweat which contains water and salts, the other substances being so small that they are neglected; (3) The products of respiration consisting of CO_2 and H_2O, together with some H and carburretted H from the alimentary canal. In estimating the expenditure care must be taken to estimate the N in the urine, neglecting any supposed N loss by the skin or through the lungs. In connection with the estimation of income and expenditure the N, C and O represent the three elements of greatest importance, the other elements such as water, salts, etc. being of importance more as a medium of other actions than themselves valuable in providing energy. The experiments require great care and precision as the estimate of the CO_2 and the sweat is a difficult process. The methods of Pettenkofer and Voit represent the most accurate scientific means used in these experiments. They use a respiration chamber, admitting and extracting the air by a gasometer so that measurements can be made in connection with the CO_2 and H_2O eliminated as well as the O taken in. Having used these methods the results enable us inferentially to arrive at the changes taking place in connection with the food and the body system.

We do not know whether the matter which constitutes bioplasm differs in its constitution from what we find after death. This cannot be determined because we cannot find out what it is during life, to subject it to investigation, involving death. We can only determine its nature and molecular constitution and the changes through which it passes by considering the constituents which maintain its life and the products of its nutritive action. In order to ascertain the value of the materials by which the body is nourished the chief point is to find out what amount of N and C are found in them. Proteids are found to contain about 15 per cent of of N and 50 per cent of C, 6 per cent of H and 23 per cent of O and S. In carbohydrates there is about 40 to 45 per cent of C and in animal fat 76 per cent of C. The purpose of nutrition is to maintain the normal proportions of these.

The various processes of digestion, secretion and excretion having been discussed and the functions which are concerned in these, we come to consider the statistics of body income and output. The ingesta include all matters introduced into the body by the alimentary system, the respiratory system and the skin; the excreta include all that is excreted from the body by various excretory organs. If the body weight is supposed to remain stationary the ingesta and excreta will be equal. If the body weight is increased then the ingesta must exceed the excreta. There is a continual excretion from the lungs of CO_2 and H_2O; from the kidneys of urea, uric acid, water and salts; through the skin of CO_2, H_2O and fatty matters. There is also a daily loss in connection with the hair, the skin, the secretions of the stomach, intestines, the salival and lachrymal secretions, etc. The body is continually gaining O, water, albumin, carbohydrates, fatty substances, salts etc. The proximate principles of the body as we have seen consist chiefly of water, albumin, carbohydrates, salts and gases. The carbohydrates form only a very small percentage of the body weight, about one per cent, so small that they may be omitted from the estimates of the income and expenditure of the body. Volkmann estimates that in every 100 parts of the humuan body we find 64 parts of water, 16 of albumin and gelatin, 14 of fat, 5 of salts and one of carbohydrates. In analyzing the body he found 65.9 per cent of water, 4.4 of organic salts, 18.4 of C, 2.7 of H, 2.6 of N and 6 of O. The muscles of the body contain 75 per cent of water and about 22 of albumin and the muscle constitutes about 43 per cent of the body weight, the voluntary muscles about 42 per cent, adipose tissue 18 per cent, skeleton 15.9 and the rest of the body 24.1 per cent. From this it is evident that 50 per cent of the water and albumin of the body is found in the muscles.

Applying these methods we will now examine into the exchanges that take place in connection with the chief food elements. (1) WATER.—This is present in all the tissues forming about two thirds of the body weight. The amount of water is estimated by deducting from the amount of water taken in as food or drink the amount of water excreted by the intestines, the lungs, the skin and the kidneys. That the water has an important effect upon nutrition is evident from the fact that if an increased supply of water is taken there is a urea increase that cannot be accounted for simply by the fact that the water washes it out. (2) ALBUMINOUS MATTER.—The nitrogenous matter excreted as urea, uric acid etc., must be estimated and from this an estimate is formed of the amount of such nitrogenous substances which undergoes change in the metabolic processes. The N of the body is found chiefly in the muscles, glands and nervous system and in the connective tissues. The proteids contain about 15 percent of N, 20 of O and 7 of H. The amount of nitrogen used up in the alimentary canal may be estimated by subtracting from the amount taken as food the amount in the faecal discharge. In albumin it is estimated there is about 16 per cent of N; therefore one part of N will be equal to 6 and one-fourth of albumin. According to Voit one gram of N represents 30 grams of flesh substance. As we saw the result of feeding almost entirely upon nitrogenous food is to increase the N body metabolism as well as the non-nitrogenous. Where the nitrogenous food is large the proteid is split up into a urea producing element and a fat producing element, the former being eliminated at once and the latter stored in the body. This accounts for the largely increased urea excretion when proteid is taken. When a large proportion of proteid is taken as food there results a large-

ly increased body metabolism, resulting in throwing off waste as urea and also tending to preserve the normal proteid metabolism of the body. This would correspond with the distinction referred to before between circulating and tissue proteid. It is claimed that the circulating proteid contributes to the heat production while the tissue proteid contributes to the tissue formation. The albuminoid, gelatin, cannot be substituted for proteid but when present in the food it seems possible to establish the N equilibrium on a lower scale, the gelatin evidently protecting the proteid of the body from the metabolic process. According to this gelatin becomes divided into a urea element and a fat element, like the proteid, being able to prevent the immediate destruction of the proteid.

(3) FATS.—In the case of fats if we subtract the volume of C from the albumin passed through the metabolic changes, the albumin containing 53.5 per cent of C, from the amount of C excreted by the intestines. lungs skin and kidneys, the balance will represent the C that has passed through metabolism. In the fatty substances there is about 76.5 per cent of C, the C of the body being contained chiefly in the fat which represents a large part of the water-free substance of the body. In fat we find about 12 per cent of H and 12 per cent of O. Fats and carbohydrates alone cannot sustain life for any length of time. Hence their nutritive function is accessory to the proteid. If a normal quantity of proteid is taken along with a small quantity of fat all the C is found in the excreta and there is no fat storage. By increasing the fat there is a point reached in which fat begins to be stored. Similarly if the carbohydrate is small there is no fat storage, but as it becomes increased regularly there is a storage of C as fat and glycogen. The fats and carbohydrates therefore differ from the proteid in that they do not stimulate nutrition to the same extent. In experiments in connection with a pig it was found that for every 100 grams of fat taken in the food, not as fat, 470 grams of fat were added to the body; while for every 100 grams of actual fat and carbohydrate substances only 20 grams were added to the body. As we have said the use of fat and carbohydrate lessens the necessity for proteid food, for example in one case of giving 800 grams of proteid and 160 of fat the N excretion was the same as in the case of another dog fed 1,800 grams of proteid alone. In the case of a fixed amount of fat and carbohydrate, by increasing the amount of proteid there is an increased C consumption, so that the proteid increases the non-proteid as well as the proteid metabolism. For this reason a large excess of proteid in the food instead of being nutritive is destructive of the fat already stored in the body. As to the difference between fats and carbohydrates, the carbohydrates require only enough O to unite with C, sufficient O being in the carbohydrate to unite with H in forming water; whereas the fats require more O, in other words O to combine both with C and H. In herbivora, therefore, we find a larger amount of O is consumed, resulting in a large CO_2 excretion; whereas in carnivora a larger amount of the O unites with H to form H_2O. This furnishes what is called the respiratory quotient, the CO_2 excreted divided by the O consumed representing in carnivora about .6 and in herbivora about .9.

(4) SALTS.—By making an estimate of the salts in the food and subtracting from it the salts excreted in the urine and faeces we get the amount which passes through metabolism in the body. All food contains both organic and inorganic salts, essential for the body although not energy producers, chiefly associated with the metabolic functions of the

body. This is evident from their distribution in the body, sodium and chloride being found in the blood serum, potassium and phosphates in the red corpuscles. Phosphorus is also necessary especially in the lecithin and fats in connection with the nervous system and with the nuclein and proteid or muscle tissue. Sulphur is a necessary element of proteids being possibly excreted in keratin in connection with the skin and the hairs. It is possibly associated with the nutrition of these corny tissues. The absence of these salts seriously affects nutrition, the metabolism of the central nervous systen being seriously impaired resulting in weakness, paralysis and often spasms. All that is known is that certain proteids depend upon the presence of salts for their metabolic reactions, this being true both of the inorganic and organic salts. If we take an animal during partial starvation in which only one or two substances are given as food the expenditure will be easy to determine, for example, where water only is given, with of course a supply of O. In the case of a man who abstained from food for days at a time the loss per day was found to be 890 grams of water, 78 of albumin, 215 of fat. It is found that during starvation the amount of N decreases until it reaches a steady limit, the loss of N being in direct ratio to the loss in the body. The loss of CO_2 is diminished at first below the ratio of the O absorbed, until it reaches a limit which remains constant untill death results. It is estimated that when an animal is starving the loss may be represented as follows; supposing the total loss to represent 100, there will be a loss of $66\frac{2}{3}$ parts of water, 25 parts of fat and $8\frac{1}{3}$ parts of albumin. If water is furnished equal to the loss of water then the loss in the other substances will be reduced between 60 and 70 per-cent, indicating that life can be sustained longer upon water alone than any of the other proximate principles. In the case of food given to supply the loss it is found that if albuminous materials are given equal to the loss of albumin, the loss of albumin is not arrested for the N in the urine increases and the body loss still continues. This is due to the increased metabolism of the body which can use up a larger amount of albumin. In the case of the dog it is estimated that from two to three times as much of nitrogenous matter must be given as food as we find excreted. Voit has estimated that to restore equilibrium and to prevent body loss one-twentieth of the body weight must be given in the form of flesh food, if more than this one-twentieth is given then the animal begins to increase in weight and there is less nitrogenous waste eliminated. If however a flesh diet is maintained there must be a daily increase in the amount of flesh given as food until it reaches a point where the animal will be incapable of digesting the amount of flesh that must necessarily be taken in order to preserve this condition. It would seem that if the albumin is increased the loss of fat is diminished. If no albumin is given as food the use of large quantities of fat does not diminish the albuminous metabolism simply diminishing the fat loss. Similarly the use of large proportions of carbohydrates does not diminish the albuminous metabolism but there is an increase in the excretion of water. If both albumins and fats are given freely as food the albuminous metabolism is diminished. Thus a combination of fat and albumin in the food tends best to preserve nitrogenous equilibrium. The carbohydrates like the fats used as food tend to preserve the albumin. For this reason the carbohydrate food in animal feeding preserves the albuminous balance at less expenditure than by the use of fats.

Voit and Pettenkofer estimate the income and expenditure in the case

of a man weighing about 154 lbs. [1] When performing active work, when the metabolism is complete. Income—137 grams of albumin, 117 of fat, 352 of carbohydrates and 2,266 of water, representing 19½ grams of N and 315½ of C. Expenditure in urine, faeces and by the lungs—19½ grams of N, 336½ of C with 2,700 of water. [2] In the case of a healthy individual not actively engaged in work. Income—137 grams of albumin, 117 of fat, 352 of carbohydrate, 2,016 of water, representing 19½ grams of N and 315½ of C. Expenditure in urine, faeces and through the lungs, 19½ grams of N, 275½ of C and 2,190 of water. In the first case there was an excretion of 434 grams more of water and 20 grams more of C than that represented in the income, while the amount of N was not increased. Therefore, in order to prepare a man for active work so as to compensate for the loss of C more fats and carbohydrates must be given in the food. In the case of the person not actively working but healthy there is a loss of 174 grams of water, but 40 grams of C are stored up in the body. This has an important bearing upon dietetics for the C producing substances in the food may be lessened, that is, the fats and carbohydrates, in the case of a person not actively engaged in work. Burdon-Sanderson tabulates the income and output as follows: Income—proteid 100 grams, fat 100 grams, carbohydrates 250 grams, representing N 15½ grams and C 225 grams; output—urine 14.4 of N and 16.6 of C, faeces 1.1 N and 10.84 of C and respiration 208 of C, representing 15½ grams of N and 225 of C. The temperature has also an important bearing upon the body metabolism and nutrition. If the atmosphere is cold the CO_2 excreted is increased and there is needed in the food more fatty substances. If the atmosphere is warm less CO_2 is excreted and less fatt substances required in the food. The nitrogenous matters are not affected to any great extent by the hot or cold temperature.

It is impossible to say exactly what becomes of the food in its different elements. The ultimate purpose of all food is to nourish the bioplasm, all the food taken contributing its share to the maintenance and building up of the bioplasm. In addition to nourishing the body tissues, the food elements furnish the materials for chemical manufacturing purposes, such as production of fat, glycogen and the substances of the various secretions, these being utilized in the production of energy and heat. In the case of food taken an analysis may be made of its division into, (1) food elements that are never brought into the tissue organism, being discharged as faeces; (2) certain elements which as quickly as they are absorbed are excreted, including saline substances taken in excess of the necessities; (3) materials which are split up within the intestines to assist in the rapid excretion, excess of proteid; (4) materials absorbed in connection with the blood and lymph and circulating in the tissues; [5] substances which when absorbed become part of the bioplasm, and [6] those materials which after being assimilated to the bioplasm are stored up in the reservoirs of the body, such as fats in connection with adipose tissue.

INCOME AND EXPENDITURE OF O AND H.—The O taken in respiration and in the food is given off as CO_2 from the lungs, to a slight extent as H_2O through the lungs, kidneys and skin and as urea in the urine and faeces. The H taken in along with the food is eliminated largely as H_2O and to a slight extent as urea. The H and O taken in water are excreted as water without being changed. There is, however, a process of water manufacture going on in the tissues in connection with H oxidation. It is well known that the burning of H produces water. All the O taken in does

not disappear as CO_2, the remainder of the O being used in the H oxidation. In the carbohydrates there is sufficient O to unite with H in the formation of water. In the fats there is the H that is oxidized by the O with a deficit of O. It is estimated that in 100 grams of fat there is a deficit of O for oxidation of 80 grams which must be taken in in other ways. There is also an O deficit in proteids. In 100 grams of dry proteid there are 15 grams of N, seven of H and 21 of O, requiring 28 grams more O for oxidation, therefore representing a deficit of 28 grams of O for 100 of proteid. Taking 140 grams of proteid as the normal daily diet of a man along with fats and carbohydrates this would represent in proteids an O deficit of 39 grams. This, together with 80 grams required for the fat oxidation of 100 grams of fat would represent 120 grams of O as a deficit; and since the carbohydrate has no deficit this would represent a total O deficit of about 120 grams. In the formation of water about one gram of H is equivalent to about 9 grams of H_2O. In 140 grams of proteid and 100 of fat there are about 22 grams of H and in 350 grams of carbohydrate about 21 grams of H. This would make in all 43 grams of H which becomes oxidized in the body daily in a normal diet in connection with the formation of water representing about 387 grams of water. This wonld represent only about 14 per cent of the water excreted from the body. What accounts for the balance of the water, 86 per cent? Even in the case of the deprival of food and water it is found that the tissues contain more water than in normal conditions. In other words there must be a water production within the system. If the statement of Solis-Cohen is true "that the cells of the body are aquatic in their habits" a large quantity of water is necessary in order to satisfy these conditions. These conditions can be satisfied only by the production of water within the body system on a very extensive scale, involving as it does the synthesis of O and H. Nature's ability to combine O and H forms the basis of this water formation, the lungs representing a large water generator as well as a gas generator for the body. That this is true is proved by the experience of animals that never drink any water.

SECTION III. General Nutrition and the Nervous System.

We have seen that the tissues of the body are nourished in connection with the materials found in the blood and lymph, these fluids carrying off the products of metabolic process. The blood receives its nutrient matters from the alimentary canal and the lungs, the waste matters being excreted by the excretory organs. In passing through these processes the food and the waste matters pass through several intermediate changes. The changes of a metabolic character take place partly if not altogether in the tissues and not in the blood as it flows from the heart to the tissues. There are definite blood changes taking place in connection with the blood and its constituents, the corpuscles and the plasma; but these are independent of the metabolic changes taking place in connection with the food elements. Taking the nutrition of muscle as a represenative of the nutrition of the other tissues, we have found that muscles live upon proteid, fat and carbohydrate together with water, saline substances and the O introduced in inspiration. As we have seen the proteid is taken up by the muscle in serum-albumin form, the sugar in dextrose form and the fats probably also in dextrose form as we have seen

that the body has the capacity of transforming fats to carbohydrates the C being brought to the tissues in dextrose form. In addition to the albumin and dextrose there are salts which are necessary to muscle energy in order to secure favorable conditions for metabolism. When these substances are metabolized in connection with the tissue, the end products are discharged into the lymph and through the lymph carried to the blood.

Here arises the question of nutrition proper, what relation do these processes bear to the tissue structure? It can hardly be supposed that at one and the same time all the tissue substance is undergoing change; nor can we suppose that the changes taking place in the muscle fibers are the same as those taking place in the inter-fibrillar substance. If this is correct there must be two phases of the nutritive process in connection with the muscle, namely [1] those taking place in connection with the direct structural material, [2] those in connection with the intersticial substance. The histological structure gives a foundation for this theory, because there is an essential difference between the framework and the substance filling in the framework. The framework of the tissue represents perhaps the most definitely formed part of the tissue, and yet it does not represent to the same degree the energy producing function; whereas the intersticial substance connected with the framework substance represents more of the matter subjected to metabolic action in connection with the liberation of energy. Both elements of the tissue pass through metabolic processes and contribute their share to the sustenance of life but the intersticial substance really in a more direct way than the frame work substance. The proteid metabolism represents the mainstay of the nutritive process as is evident from the fact that the N excretion represents the end product of the metabolism. In the case of vegetable nutrition the mass of material is starchy or carbohydrate, although this very soon becomes changed to a delicate proteid fiber, the metabolic products being interspersed between the fibers. These minute fibers are at the basis of all the metabolic changes, the nitrogenous products being stored up within the plant. On this analogy in the human tissue the nutritive changes will be found to take place largely under the direction of the framework substance, while the most of the changes take place in connection with the intercalated substances, both of these processes representing general nutrition. In the case of the fibrous tissue the changes are much slower and less extensive, the intersticial substance representing the continuous changes taking place in the substance preparatory to the fiber changes. In connection with these metabolic and nutritive processes the central nervous system exercises the controlling influence. The nervous control is manifest in muscle contraction, in secreting gland activity. In the case of muscle contraction there is a dissolution of more complex bodies into simple substances, but this does not exhaust the nervous action, for it bears equally upon the upbuilding process. If a nerve that goes to a muscle is stimulated the contraction is subject to the control of the nervous mechanism under the influence of the stimulation applied. This indicates the fact that the nervous system regulates the metabolic and nutritive processes, even aside from the fact of contraction and relaxation. If the nerve connection of a muscle and the central nervous system is severed there is muscle degeneration and loss of vitality. As we saw when the nerve connection to the sub-maxillary gland is entirely severed there is a paralytic secretion emitted from the gland

taking place until the gland degeneration results. If in a dog the fifth nerve is divided inside the skull there is a loss of sensation in the part of the face controlled by the nerve and it is accompanied by nutritive changes of an important character. There is noticed first of all a haziness in the transparent anterior portion of the eye-ball, followed by inflammatory conditions that lead to the entire affection of the eye; these are accompanied by inflammation of the nasal cavity on the divided side and by ulcerated conditions of the buccal cavity and of the lips. If this takes place in a young dog which continues to live it is found that the skull becomes unsymmetrical. It has been found that if both the pneumogastrics are divided there results an oedematous condition of the lungs, accompanied by fatty enlargement of the heart finally resulting in death. Where the fifth nerve is divided the loss of sensation deprives the eye of protection from foreign substances and it is said by some that if the eye is concealed so as to prevent irritation from these foreign matters the inflammatory condition of the eye may be prevented, This has been denied by others who say that the nutritional changes involved produce the inflamed condition.

In the case of lung inflammation resulting from a division of the vagi, it is said that the inflammation arises from the partial paralytic condition of the œsophagus and pharynx resulting in a stoppage of food and its being driven into the bronchial tubes producing irritation. In support of this it is claimed that death frequently results in these cases from starvaiton because on account of œsophageal paralysis no food can reach the stomach. It is more likely, however, that there are certain nutritional changes involved in connection with the lung tissues by reason of cutting off the pulmonary branches of the vagi. Where we find pathological conditions of the spinal cord we find in certain cases a quick degeneration of the skeletal muscles producing the loss of muscle contractility, the degeneration in the muscles being more marked than in the cord and in the nerves supplying the muscles, evidently due to nutritional changes. In the case of cerebral appoplexy we find an acute muscular condition giving rise to morbid conditions represented by peculiarly delicate sores. In the case of spinal and cerebral injuries we often find acute conditions of the bladder due to the lack of nutrition; in cases where the nerves are crushed the degeneration of the muscles and the loss of contractility is more rapid than in cases where there is simply division of the nerve fibers; skin eruptions are found associated with nervous diseases and in certain skin diseases. In zona associated with intercostal neuralgia we find an accompanying eruption both the eruption and neuralgia indicating neuritis, in which changes have been found in the nerves and in the ganglia of the posterior roots of the spinal cord.

In acute tonsilitis we sometimes find developed erythema with paralytic symptoms either local or general. If one of the forms of the grain disease or grain poisoning called Pellagra, a disease found often in Italy and in the South of France and Spain, arising from the use of maize that is diseased or has become feremented, associated with Erythema is weakness and spinal pains together with stomach conditions; where the disease is acute the nervous symptoms become very pronounced resulting in paralysis and mental disturbance. All these represent interference with nutrition arising in connection with the nervous system. It cannot be doubted that the nervous system exercises a trophic influence upon the tissues. The trophic changes may exist alone or they may be accompan-

ied by cerebral, spinal or central affections. This indicates that it is not necessary that there exist diseased conditions of the centers or ganglia but that diseased conditions of the peripheral nerves may produce such nutritional changes. Secretory abnormal conditions associated with the sweat and sebaceous glands, as seborrhœa, anidrosis and hyperidrosis, all of which are of nervous origin in connection with the brain, the spinal cord or the peripheral nerves, represent similar nutritional changes. In connection with these as examples of changed nutrition may be cited the peculiar fingers of phthisic patients, the symmetrical gangrene condition of the fingers and toes, in the last case the fingers seem at times to be dead while at other times they become very red colored, the nutritional changes at first only temporary becoming permanent, resulting in sores, loss of nails undoubtedly of nervous origin. Of the same nature are the changes found associated with the loss of sight in which there is found a close connection between sensations of light and the nutritional changes in the skin. That this is due to nervous action is evident from the fact that the deprivation of light materially affects metabolism, indicating the nervous action in connection with the light sensations. Even if we take account in these of vaso-motor action, of the peculiar forms that sensation may assume and of the absence of the necessary changes taking place in the muscular contraction, we have still left conditions which cannot be accounted for unless on the basis of a nervous action in connection with the muscles quite different from muscle contraction, under the influence of the nervous system. This leads us to the conclusion that the nervous system has a very close connection with nutrition and the nutritional changes taking place in connection with the muscles, glands, blood-vessels and in fact with the entire body. The general nutrition in other words of the body depends upon nervous influence.

SECTION IV. The Nutrition of the Brain.

As the nervous system is so closely connected with nutritional changes it is important to discuss the nutrition of the brain, because there must be proper nutrition of the ganglia cells and the peripheral nerve system. The brain is composed of two parts, the cortex with the medullary substance which covers over the brain and the sub-cortex including nerve centers and tracts. The irradiation that is so essential to brain activity as the center of the nervous life is based upon the accumulated sub-cortical regions in connection with the brain, ventricles and the medullary tract. In connection with nutrition the arterial circulation forms an important element. The extent of the cortex makes provision for a large number of arterioles all of which are about equal in calibre, branching off to the different brain areas. Hence the extent of the cortex and the number of arteries reaching down into the cortex from the pia mater become the basis of changes in the circulation representing possible hyperæmic conditions of the different cortical regions. This makes it possible for the supply of nutrition in connection with the blood in the cortical centers to be in excess of the nutrition supplied in the blood in the other cortical regions, resulting in the activity of the cortical centers while the other cortical regions are practically resting. This is based upon the localization of areas in the brain and the practical independence of circulation in these different areas. In connection with the psychic activity of the brain we find areas that are separated widely from

one another functionally very active at one and the same time, involving a hyperæmic condition of the blood.

Brain nutrition may be said to be divided into two phases, that during sleep and during wakefulness. In sleep there is general diminished activity. This does not imply that to be awake involves increased activity throughout all the brain areas. Fechner considers that wakefulness represents a more or less partial activity involving more or less partial functional activity, so that during the time the individual is not asleep the different parts of the cortex are in different stages of activity, some of them being in practical rest. The brain activity can not be explained by dividing up the brain into a number of parts each discharging a part of the brain function and all the parts receiving an equal blood supply. In the case of the other body organs we find that, for example in the liver and the lungs, these organs receive in all their parts an equal supply of blood when normal. With the brain, however, it is different because all the parts of the brain are never acting simultaneously, and hence the difference in function forms the basis for the difference in blood supply to the different parts of the brain. The supply of blood is determined by the functional activity of the areas, in this case DEMAND REGULATING SUPPLY. In the case of other organs of the body this is not true, because the blood supply in these organs is limited only by the capacity of the organs represented in the membrane propria or the tissue substance. In the case of the brain it is different. The skull represents an immovable anatomical structure limiting the capacity of the blood circulation in the cerebral vessels, so that the anatomical structure regulates to a large extent the circulation of the brain and hence the nutrition of the brain. The skull for example governs the blood pressure within the cranial cavity. Inside the cranial cavity there is a possibility of functional increase depending upon one of two things, [1] A removal of the blood from the venous circulation towards the sinuses so as to give free arterial action: or [2] The establishment of some collateral arterial circulation. The first condition would be a slow process and could not be continuous because the venous flow would depend upon respiratory activity; whereas the latter would represent a condition difficult to maintain from the standpoint of brain anatomy.

It is easy of explanation if we recognize that the brain substance does not entirely fill up the cranial cavity; but that there are lymphatic channels as well as lymph reservoirs in the skull. On this basis we have a foundation for a theory which accounts for the partial change in the arterial blood circulation and distribution within the brain. In the roof of the brain we find distinct grooves representing indentations made by the brain convolutions in development. Why do we not find these same modifications in the sphenoid bone at the base of the brain? This is evidently explained by the fact that nature has provided lymphatic channels among other functions which they discharge to form a more or less yielding base upon which the base of the brain may rest, without imposing its weight upon a solid bone foundation. Here we have a part of the economy of nature that is closely connected with brain nutrition, providing for arterial dilatation within the brain substance of the cranium. The necessity of this is easily understood when we consider that the brain is not inactive but that there are certain rhythmic movements of the brain substance within the brain cavity comparable to those of the spleen and liver associated with their nutritional changes.

Buckhardt demonstrated the existance of three such variations, (1) corresponding with the systole and diastole of the pulse; (2) corresponding with the inspiratory and expiratory phases; (3) corresponding with the vascular variations as these are regulated by the vaso-motor center. The brain movements and the blood pressure within the brain are dependent upon these three forces. At the same time normally there is no brain compression, because of the activity of the lymphatic fluid which yields to the cranial movements, preventing any concussion. In connection with brain nutrition there are two things that require to be considered, (1) the variations in blood supply to the brain depending upon anatomical and physiological conditions; and (2) The brain activity represented by these brain movements as regulating the blood distribution and therefore brain nutrition. Both of these influences are essential to a perfect brain nutrition and to the normal brain function.

1. The variation in the brain represented by certain movements is rendered possible without an abnormal compression on account of two facts, (1) the existance of the lymphatic reservoirs which yield to the brain movements; and (2) the existence of the venous spaces contiguous to the sinus longitudinalis, these spaces being separated simply by delicate membranous endothelium. These represent spaces lying between the filaments of the dura mater tissue. Pathological conditions of these spaces are found in connection with the foveae glandulares in cardiac and senile conditions. The physiological functions of these cavernous spaces is to fill the brain cavity, becoming enlarged inanæmic and contracting in hyperaemic brain conditions.

The arterial circulation of the brain may be divided into two parts, (1) branching from the meningeal and [2] branching from the cerebral arteries. The branches found in connection with the sulci arteriosi of the flat basilar bones are the nutritional arteries for the outer membrane of the brain or of the portion which forms the nutritional membrane of the cranial bones. The dural membrane arteries are divided into an external and internal mesh-work, the former throwing the blood into the capillaries of the dural membrane, the latter emptying immediately into the large veins without passing the blood through the small capillaries, in this way preventing a hyperaemic condition from being developed in the dura in normal conditions. The blood of the arteries and veins of the pia mater has a direct communication on the vascular membrane of the brain, in this way permitting the arterial blood to cross the cerebral cortex in large volumes and so preventing a large volume of blood in its passage from the arteries to the veins taking place beneath the surface membrane. This makes provision for the brain nutrition so as to provide a direct passage for the blood to and from the lymph vessels. The outer lymph space is represented in the brain cavity by a small space between the dura and the arachnoid, communicating directly with the lymphatic glands in the neck and also with the lymph spaces of the peripheral nerves, especially those of the optic and auditory nerves. The sinus venous spaces and the lymph spaces in the dura also communicate with the outer lymph spaces. In the arachnoid membrane which surrounds the brain and separates the subdural lymph space there is a net work connection with the piamater which admits of close connections between all the subarachnoidal spaces. On the cortical surface we find several reservoirs all of which provide accomodation for lymphatic collection, the description of which is found in theanatomy of the brain. The fore brain arteries

spring from the carotid and vertebral arteries the former supplying with blood the anterior and middle cerebral.

According to Buckhardt the general relations between the blood vessels and the membranes of the brain establish the basis for the nutrition of the entire brane. His theory in regard to the pulse, respiratory and vascular variations simply carries out the circulatory principles as applied to the rest of the body, the pulse wave indicating arterial force, the respiratory wave representing venous blood in connection with aspiration determining the blood to the heart and the vascular wave representing the vaso-motor action in connection with the dilatation and contraction of the arterioles. In connection with the vaso-motor action there are, as Riegel states, peristaltic movements of the arteries giving rise to rhythmic contractions, these being possible on account of the space surrounding the brain occupied by the lymph and cerebro-spinal fluid. There is considerable pressure within the brain as is proved by the fact that by using the pulsometer in connection with a protruding part of the brain very accurate and definite tracings can be secured, these tracings corresponding exactly with the carotid pulsations. The pressure is neutralized to a limited extent by the cerebro-spinal fluid in the cavernous cavities. In connection with respiration we find the depression and elevation of the pulse wave depending upon the variation in the venous blood pressure. In connection with the vaso-motor action the vascular wave represents a hemispherical dilatation and contraction of the brain mass. This variation occurs most regularly during sleep, during wakefulness the variation being irregular. These variations do not depend upon the pulse or the respiratory actions for they produce varations in the pnlse and respiratory waves of the brain. For this reason the vascular changes of the brain represent the most important element in the blood circulation and brain nutrition. When the vascular contraction of the brain takes place the pulse and respiratory actions are lessened on account of arterial contraction, the reverse being true of vascular dilatation. In connection with these vascular variations of the brain it is found that when stimulation is carried to the brain these vascular variations are interfered with, psychic influences producing dilatation, while pain or excessive sensory stimulation produces a contraction of the brain mass.

One important point brought out by Buckhardt in connection with the vascular variations was that they were peristaltic in character. He pointed out the importance of this from a nutritional standpoint, the peristalsis in connection with the brain substance as it is brought into contact with the rigid cranial cavity which acts as a mechanical motor power in driving off the waste products through the lymphatic circulation, originating and keeping up a lymph flow throughout the brain. The arterial contraction originates at the circle of Willis, produces a contraction at the base of the brain raising it from the base of the cranium and driving the blood forward into the brain substance through the superior arterial ramifications. This contraction starting from the base of the brain pushes the brain upward towards the roof of the skull, cutting off the advancing cerebro-spinal fluid; at the same time part of the ventricular fluid is driven through the Magendic foramen into the sub-arachnoidal space, the ventricular roof being compressed by the dilatation of the upper hemispheres which press closely against the cranium. Following this we find the contraction of the superior cerebral arteries along the skull cavity. Accompanying this is the dilatation of the basal part

of the brain, the ventricular fluid being driven beyond the upper cerebral portions of the brain into the sinuses and the Pacchionian granulations under the duramater and finally into the basilar nerve sheaths and the lymphatics of the cervical glands. While the contraction exists in the hemisphere the ventricle is dilated, this dilatation resulting in secretion of the ventricular fluid connected with nutrition. In this way it seems plain that the vascular variations of the brain account for the lymph circulation. During sleep these variations are regular, indicating that the refreshment arising in connection with sleep depends upon the free circulation of the lymph carrying nutriment to the brain and carrying off waste products from the brain. During wakefulness the variations are irregular, indicating that the variations throughout the brain areas are not uniform but that the contraction and dilatation take place in different areas at different times, just as we know to be the case with the capillary system throughout the body under the vaso-motor control.

The nutrition of the brain then depends upon definite changes in the brain, these being regulated by certain movements in which the lymph and blood play a most important part. We must consider the chemical composition of the materials of the brain and of the substances in the nutritive processes. It is difficult to get correct chemical knowledge of the brain itself especially in the distinction between the gray and white matter of the brain substance. The fore brain consists chiefly of the white matter, the brain trunk being chiefly composed of the gray matter. Danilewski found that the gray matter varied in its specific gravity from 1029 to 1038, the white matter from 1039 to 1043, estimating that in the human brain there is from 27 to 39 per-cent of gray matter and from 61 to 63 per-cent of white matter. In the dog he found the gray and white matter in equal proportions. This is due in animals not to the number of cells but rather to the amount of connective tissue of an albuminous nature and without framework form found in the brain. In regard to the matter of the nerve cells found in the brain they are exactly similar to the axis cylinder of the nerve, responding to the reaction for albumin. In connection with the nuclei of the cells is found nuclein a larger proportion of it being found in the gray than in the white matter. Thus we have albumin and nuclein in the brain substance and this implies the presence of phosphorus, the albuminates and phosphates uniting in connection with the formation of the brain connective tissue. A fresh brain has been found to contain .49 per cent in the gray matter and .89 per cent in the white matter, the entire nervous system containing 12 grams of phosphoric acid according to Voit, Of water there is 81 per-cent in the gray matter and 66 per-cent in the white matter. Of the other substances in the brain large quantities of inosit, lactic acid, kreatin with lesser quantities of uric acid, xanthin, urea, leucin are found. The reaction of the brain as a whole is slightly acid, of the white substance neutral, the brain giving an acid reaction after death and the white matter an alkaline reaction.

The cyanides are developed in connection with the metabolism of the cells, the failure to throw off these resulting in epileptic conditions. One of the principal substances of the brain is protagon containing like nuclein phosphorous which is really a compound substance according to some consisting of lecithin, cerebrin, encephalin. It is one of the main brain constituents splitting up at a temperature below 100 into glycerine, phosphoric acid, fatty acins and neurin. Pratagon is an important element accord-

ing to most recent physiologists in the brain substance because it is closely associated with the property of conductivity in connectiou with the nerves. Conduction takes place in the non-medullated fibers as well as in the medullated fibers.

In the case of the motor nerves when divided they degenerate towards the central nervous system from which they have received their stimulation, the sensory nerves degenerating towards the periphery from which the sensory stimulation started.. The nutrition of the nerve fibers is dependent upon the non-medullated tissue in connection with the axis cylinder, receiving both central and peripheral stimulation, the stimulation exciting the nutritive changes. The axis cylinder has a strong influence on the nutritive fluid, the stimulation causing the nutrition to become effective. Thus the medullated substance assists in the nutrition of the axis cylinder and also in developing the principle of conductivity associated with the nervous system. The medullated substance would be connected with the oxidation process in connection with the venous blood as it leaves the brain, the medullated substance having the power of extracting O out of compound substances, the phosphorus being an important element in this process of O extraction. Conductivity is a slow process, as Kuhne points out, on account of the slowness of the chemical changes taking place along the nerve during the process of conduction. It is the axis cylinder alone that can be thus active in connection with conductivity, because it alone represents a continuous path. The medullary sheath is non-continuous on account of the Ranvier nodes. It has been shown that if the axis cylinder is swollen by immersion in water the current is arrested in the white substance at the nodes while in the primitive sheaths no such arrests take place. The white substance is segmented, the segments being connected together, the partitions dividing these segments containing corny tissue representing a network of keratoid substance. The keratoid substance is favorable to nutrition, the substances found associated with it aiding the endosmosis in connection with the nutritive fluid. The axis cylinder while subjected to stimulation seems to attract chemical substances from the white tissues, intensifying the chemical processes associated with conductivity, the sheath representing an osmotic membrane which permits the nutritive fluid to pass from the white substance to the axis cylinder, the passage taking place slowly. This sheath represents a regulator of the nutrition of the axis cylinder as well as its protector. The same is true of the white substance of Schwann. The white substance in its nutrition is thus entirely independent of the fluid passing from the blood vessels. The large number of interruptions in connection with the corny substance in the white substance renders the nutrition process slow, the fluid oozing along gradually from one segment to another,

The changes taking place in connection with the nutrition of the nervous system have been investigated chiefly in connection with the phosphoric excretion from the body, the nervous system being supposed to account for a large proportion of the phosphorus excreted in the urine and faeces. Comparison has been made of the phosphorus excreta during sleep and wakefulness, the urine having more phosphoric acid during sleep, from which Mendel has concluded that the nervous elimination of waste matters is greater during sleep, a conclusion that agrees with what we have already said in regard to to the brain variations. There is a close connection between the vascular variations and the increase of the

lymph flow, the brain being characterized by irregular movements during wakefulness, the explanation of this being that the large amount of waste elimination takes place from the brain during sleep. It has been found that mental activity produces an increase in alkaline phosphates excreted decreasing the earthy phosphates, indicating the increase of nerve tissue normally during mental activity or exercise, similar to the muscle increase that we found associated with exercise. Brain activity according to this involves a diminution of waste products and an increase in the process of synthesis going on in the brain substance. During rest there is an increased decomposition resulting in the rapid removal of the waste products. Hence, it is inferred that the functional activity of the axis cylinder drives out phosphorus from the white substance, this phosphorus being used up in the chemical processes; within the white substance, however, these processes are diminished, representing a resting condition. The horny sheath of keratoid associated with the axis cylinder and the white substance is of value in the nutrition of the nervous system, chiefly on account of the pressure which it excites. In the case of the brain and the spinal fibers the Schwann sheath is absent, its absence being compensated for in the brain and spinal nerves by the larger amount of fluid exudation. In connection with the axis cylinder, which we have seen is independent from a nutritional standpoint, it seems to be necessary in order to sustain the function of the axis cylinder against hyperæmic cerebral conditions as well as to protect the brain from anæmic conditions. In the case of the gray matter the large water composition has a different function from that of the axis cylinder in which it acts as a conducting medium through the peripheral nerves and the white substance of the central nervous system. In the gray matter the albuminous substances are found in large proportions and also large quantities of phosphorus, because the phosphorus seems to accumulate in the gray matter of the brain. There is also a larger quantity of nuclein found embedded in the cells, the nuclein being also rich in phophorus so that it exercises principally a nutritive influence because it contains phosphorus, as well as influencing the albumin activity, preserving intact in normal conditions the albuminous protoplasm and preventing its destruction.

In the cortex we find a large proportion of plasma accumulated in the dense plexuses of the blood vessels, the nerve cell nutrition being controlled by the keratoid sheaths until the nerve fibers become surrounded by the regular medullary sheath.

In connection with the gray matter there is irradiation when different nerve cells combine for united activity, so that the thought development takes place in connection with functional association, groups of cells being associated as the basis of all the more complex associations of thought. It is here that the mental element is introduced as an important modifying influence upon the nutrition of the brain and of the entire body organism, the influence upon the body organism being communicated through the brain. There are great centers of excitation and also fibers of association, so that the localization of areas in the brain simply assists in the association of stimuli of different kinds, these different stimuli being combined by association so as to unite the cerebral activity. When the cortex of the brain becomes functionally active there is a complex chemical synthesis, requiring an increase of the plasma, the principle of attraction accounting for the distribution of the plasma the demand as we said regulating the supply. This is different from the nutrition in

the rest of the body.

In addition to this principle of attraction found in connection with the cerebral machanism, we have the active influence of the vaso-motor center regulating nutrition accounting for the increased blood supply to the brain. The vaso-motor influence is represented by the vascular variations, the vaso-constrictor action accompanying arterial contraction and the vaso-dilator action accompanying arterial dilatation. Muscular energy cannot be regarded as simultaneously produced along with mental energy, the upper part of the brain having the power of inhibition upon the functions discharged by that portion of the brain. The vaso-motor influence in regard to vascular variations we found to be associated with peristaltic action and these peristaltic movements are modified by the hemisphere activity, the activity being least during sleep when the variations are most regular. This seems to indicate that vaso-motor influence upon the brain is not direct but through the lower centers in the sub-cortical region, so that there is a possibility of the cortical and sub-cortical vaso-motor centers acting as inhibitors of each other. From this it is concluded that the normal functional hyperæmia depends upon the inhibition of the sub-cortical center by the cortical center.

Buckhardt has pointed out that emotion exercises a very strong influence upon the vascular variations of the brain. This is due to the fact that emotion arouses the widest excitation of the nervous system. The arterial contraction may be either lessened or increased, depending upon the number of the nerve elements in active operation and upon the number of those elements set free to act. In the case of the sensation of pain this is well illustrated, for example, if the foot be subjected to a very hot temperature and then the entire lower limb be subjected to a similar temperature, in the former case the nerve elements represent a smaller number than the latter so that fewer of these nerve elements are called into active operation in connection with the sensation of pain in the former case, resulting in a difference in the degree or intensity of the sensation. In the case of emotions of a repugnant character the nutrition of the brain will be retarded or suspended for the waste matters are removed from the brain under the influence of the arterial dilation, this waste being continued to such an extent as to exhaust the brain of its nutriment. In connection with the brain itself we find that the variations control the nutritive process, the circulation of the blood being subject to the muscular action of the arterial system. Hence all the brain metabolism is carried on in connection with these variations, resulting in the driving out of the ventricular fluid as well as the free lymphatic circulation in connection with the intravascular and sub-arachnoidal spaces. This is all controlled by the vaso-motor center so that the nutrition of the brain is really dependent almost entirely upon vaso-motor action.

Closely connected with the nutrition of the brain is the brain weight, varying in the human subject; in the male from 1,000 to 1,925 grams and in the female from 820 to 1,565 according to Bischoff. Pflegers holds that in the female there is a much less perfect development of the hemispheres than in the male, but this statement has not been clearly established. It is said that where the convolutions are well developed we have the indication of high nutritive conditions, indicating the degree of intelligence the complexity of the convolutions being said to represent intellectual development. This does not seem to hold good if we compare the monkey with the horse, unless we accept the explanation of Meynert that

in the case of the distinctly social animals this marks the increased intensity of their intelligence which differentiates the gregarious animal from the isolating animals. Aside from this the development of the convolutions of the brain depends upon mechanical principles. Inside the cranium the convolutions are closely packed together the development being limited by the capacity of the cavity, so that free development can only take place within the cranial dimensions. It is true that by the comparison of one class of animals with animals of other classes the convolutions do seem to bear a striking relation to the intelligence of that class of animals. There is an anatomical foundation for the true theory in regard to convolution development. For example, there is a distinguishable difference that can be observed in foetal brains between what are called the longheaded and the shortheaded foetuses, the difference being as Rudinger points out one of anatomical structure. He shows that here we have the true basis of the mechanical theory of the limitation there is said to be to brain development, the cranium and the dural membrane exerting a strong pressure on the brain substance, so that in the nutrition of the brain its shape is modified by the cranial cavity, In the case of the longheaded brain he finds a contraction at the coronal seam, representing the junction of the cranial bones, this contraction extending towards the fissure of Sylvius between the anterior and the middle lobes of the brain, producing in the brain as it develops to maturity a dural thickening at the side of the small extension of the sphenoid bone, hindering the transverse brain development. This produces excessive vertical enlargement. This is due to mechanical action in connection with the cranial development.

In regard to the development of the convolutions there are noticed differences in the convolution development about the seventh month of the intra-uterine life, the parietal convolution developing before the occipital and frontal lobes. Rudinger points out that in case of the female the development of the convolutions is less perfect, particularly in the frontal lobe; this limited development characterizes the female brain in its development towards and during maturity. Welcker thinks that the female brain tends more to the longheaded brain, this accounting to a large extent for the lesser convolution development. In these forms of the brain the vertical convolutions are not retarded in development, whereas, in the short-headed skulls it is impossible mechanically that the longitudinal convolutions can be fully extended. This is in line with the idea that brain development depends upon the mechanical development of the skull, in the narrow skull there will be little transverse development, whereas, in the broad lateral skull the vertical development is limited. Between the convolutions along the fissures we find the development of the pia mater, the brain development and its nutrition depending upon the formation of the skull. These developments or retarded developments do not seem to influence the cortical functions, because the activity of the cell does not seem to depend upon its location in connection with the convolution or a groove between convolutions. In connection with the brain canvolutions attempts have been made to explain the increasing torsion of the convolutions at the frontal and occipital ends accompanied by the free anastomosis, the medial convolutions being wider and more freely developed vertically. There is no hindrance to vertical or transverse development in the case of the median portions, whereas in the frontal and occipital region there is a necessity for the closer connection of the con-

volutions.

In the development of the central nervous system the peripheral nerves and terminal organs have an important share from the standpoint of nutrition. Gudden proved that if the sensory impulses are cut off in the case of a new born animal, by nostril occlusion and the adhesion of the lids to the eye-balls, the development of the brain will be retarded in some of its parts. This is true of the olfactory bulb, nerves and convolutions, their development being incomplete. To compensate for this lack of development, he fonnd an enlargement on the frontal region of the skull corresponding with these undeveloped portions of the brain, the contiguous brain parts having been more fully developed. He carried the experiment further by exterminating the nerve terminals, the result being a marked absence of development in the brain area and the olfactory nerves. By the removal of the olfactory bulb the anterior commissure was not affected at all, indicating that it depends for its nutrition upon the gray matter; but when the olfactory lobe along with the entire hemisphere was removed. then the anterior commissure began to atrophy accompanied by the degeneration of the corpus callosum which is nourished in connection with the cortex. After stitching the eye-lids together there was found a partial degeneration of the optic tract and nerve and the anterior body of the corpora quadrigemina on the opposite side. By the entire removal of the internal membrane of the eye there was found complete atrophy of the optic tract on the opposite side and the corpora quadrigemina. By reversing his experiments and removing the superior corpora quadrigemina there was retarded development of the optic tracts.

In the brain of the new-born child some of the medullary regions are gray instead of white the medullary sheath not being developed. Flechsig has worked out this idea in connection with foetal brain development the medullary sheath development taking place upward and marking the progress of longitudinal development in the foetus, the postero-median and the postero-external columns of the spinal cord being the first to manifest the presence of the white substance. This represents an important physiological fact in connection with functional development, the afferent nerve paths representing the key to the entire central system, indicating that the nutritional value of the peripheral nerves and terminal organs represent an important factor in the nutrition of the central system. Following the development of the posterior colums is development of the anterior columns of the spinal cord in connection with the white matter, the gray being still associated with the pyramids, indicating as Meynert says that reflex actions result from sensory developments, the sensory stimulation assisting in the development and nutrition of the central nervous system. Before the end of the embryonic life we find the development of the white substance in connection with the medulla, cerebellum, the cerebral surface of the crus cerebri, the thalamus and the mid-brain and finally in connection with the occipital and parietal lobes, the fuller development of the white substance taking place after birth, for example, in connection with the frontal lobes. This indicates the nutritional value of external stimuli in connection with the peripheral nervous system in the development of the central nervous system.

We have spoken of the cerebro-spinal fluid in connection with brain nutrition. It differs from the other serous finids of the body and is really a secretion rather than an exudation. Its composition does not vary

much even in pathological conditions. The albuminous materials are found in the albumose form rather than in the serum-albumin form, with no fibrinogen so that it does not coagulate. Sometimes there is found a very small trace of the serum-albumin. The fluid has a very low specific gravity varying from 1005 to 1010. It is this fluid that seems to be of importance in the nutrition of the brain and spinal cord.

CHAPTER IX. ANIMAL HEAT AND FORCE.

SECTION I. Introduction.

Speaking generally the body may be regarded as a mechanism for the transformation of food materials into potential energy and finally into body energy. Body heat may be regarded as a continuous evolution of kinetic energy existing in connection with the molecular vibrations of the body atoms. The metabolic processes involve the conversion of these materials into energy in the form of work and animal heat, so that the ultimate source of heat is the potential energy of the food. This conversion implies the oxidation of the food substance into their corresponding end products. It is easy to estimate the amount of potential energy contained in a normal daily diet and thus estimate the energy accumulated in the body system daily. The amount of heat depends on the amount of energy that is liberated. The food energy is a form of latent heat, this latent heat being liberated in the body. Heat is regarded by physicists as a form of motion representing a condition of matter rather than a substance, so that heat may be converted into motion and motion may also be converted into heat. The income from which heat is derived in the animal economy may be regarded as the oxidation of food elements, proteid, fat and carbohydrates. The potential energy of any body in reference to the chemical changes of the body represents the same result, however the result may be attained. By the oxidation for example of one gram of fat we have the same result whatever be the number of processes through which the substance has to pass in the production of CO_2 and H_2O. It is easy on this basis to estimate the potential energy of a certain quantity of food irrespective of the variation in the processes through which it passes.

It has been noticed from early times that the bodies of some animals are warmer than the air around. This forms the basis of the distinction made between the warm and cold blooded animals, or as it is more scientifically stated in modern times, between animals whose bodies are homoiothermal, constant in temperature and not affected to any great extent by changes of temperature in the medium, and those poikilothermal whose bodies vary in temperature from the temperature of the medium being always slightly above the medium. This distinction is fundamentally a physical one although of great importance in physiology. The higher animals, including the mammals and birds, have generally a constant temperature; some of the mammals, however, like the hibernating marmot or the hedgehog are constant in summer, the temperature being high, and variable in winter during their hibernation when they are inactive. We find also among the bees a high temperature although they do not hibernate. In the case of the cold blooded like the frog we find considerable variations; for example in summer it may be 30 degrees and in winter almost at zero and yet the tissues are not affected by these changes neither is the vital force diminished. It was formerly supposed

Subject - f... of the forms of life.

that the difference between warm and cold blooded animals was absolute, the warm blooded having always a higher temperature. That this is not so is proved in connection with the frog which has been found to possess a temperature above that of man in a high temperature of the water medium. In the case of the higher animals there is a heat mechanism in connection with the body regulating the heat production and loss, preserving a normal temperature whether the surrounding medium is hot or cold. We do not know why a higher temperature is necessary in the case of the higher animals than in the case of fishes to carry on the physiological functions. It is supposed that the extreme delicacy of the organism in the higher animals cannot endure the same amount of shock as the lower organisms whose bodies seem to be unaffected by extreme cold or heat. In the case of some warm blooded animals, for example very small children and immaturely developed animals at birth they are not able to sustain body temperature but are dependent upon some auxiliary source of heat.

THERMOMETRY AND CALORIMETRY.—When two bodies are brought into contact if no transference of heat takes place from one to another they are said to have the same temperature. If, by contact, heat passes from one to another then they are at different temperatures, the body from which heat passes being at the higher temperature. It is a well known physical law that diffusion of heat will take place between bodies of unequal temperature till the temperature is equalized. If, then, we can determine the temperature of any single body, it is easy by comparison to measure the temperature of other bodies. It is on this principle that thermometry is based. Temperature may be defined in reference to a body as the greater or less degree in which it is capable of imparting heat to other bodies. We must not confuse temperature with the amount of heat because the amount of heat in the body may be small while the temperature is high and vice versa. For example, if a pint of water is taken from a gallon of hot water the temperature will be the same but the amount of heat will be different. The thermometer is an instrument for measuring temperature. The ancients depended solely upon their sensations in estimating temperature. Our sensations, however, are liable to such errors that we cannot depend on the accuracy of the sensations of heat and cold, particularly to such a degree of delicacy as is necessary in connection with body temperature. It was at the close of the 16th century that Sanctorius and Gallileo invented the crude thermometer, the former using air enclosed in a bulb at the end of a tube containing a colored fluid, measuring changes of temperature by the expansion of the air, the latter using alcohol. It was in this form that the alcohol thermometer was graduated by Hooke and Newton. Fahrenheit in the begining of the 18th century was the first to substitute mercury for alcohol, graduating the thermometer as we have it now associated with his name. About the middle of the 18th century Celsius invented the centigrade thermometer. The mercurial thermometer contains a quantity of mercury in a small glass bulb, the bulb extending into the tube in a very delicate stem. The expansion is measured by a graduated scale usually attached to the glass tube. Mercury expands with the rise of temperature and contracts with a fall, the rise and fall being indicated upon the scale. In the C scale the point marked by the mercury when its bulb is immersed in melting ice is called zero; the point marked when it is placed in the medium of steam arising from boiling water is represented as 100 degrees. In

using the thermometer in connection wtih an animal or man the thermometer is placed in contact with the part to be measured until the mercury becomes steady, indicating that expansion or contraction has ceased. This does not give us any indication of the amount of heat in the body or in its part, because we have simply measured the capacity of the body to give out or take in heat, representing the tension of the heat or the intensity of the heat of a substance. In connection with an animal the measurement is usually made in connection with the mouth, the rectum, axillae, the external ear or the vagina. The skin temperature may be measured by using the ordinary mercury thremometer, covering the bulb with some non-conductor of heat, as there is error if the bulb is left uncovered. A more perfect result may be obtained by the use of a resistance thermometer which is formed from a grating of lead paper or tin foil. The increase of temperature produces an increase of the resistance of the lead or tin foil, disturbing the balance of Wheatstones bridge which is connected to the lead by wire. This instrument is specially of value in determining variations in skin temperature over different parts of the body.

In order to supplement the work of heat measuring associated with the thermometer physical science has introduced the calorimeter. The amount of heat that an animal produces can be estimated by measuring the heat given off and also the heat equivalents of the changes taking place in the body. To be exact both of these must be estimated. The quantity of heat is estimated from the weight, the specific heat and the body temperature. The object of the calorimeter is to measure the qunatity of heat which passes off from the body or into the body when there is a change of temperature in the body. Quantities of heat are most conveniently measured by estimating their capacity of raising the temperature of a known standard such as water. Many attempts have been made to con struct calorimeters but only in recent times have these been successful with exact methods. In some cases as in the ice calorimeter of Laplace and the ether calorimeter there is a changed condition represented by ice liquefaction and ether evaporation, so that the heat is measured by these processes of liquefaction and evaporation. These are not exact, especially the ice method, because to expose to an ice temperature implies loss of heat.

The unit called the thermal unit is the amount of heat required to raise the temperature of one gram or C. C. of water one degree C. This is called a calorie. The unitof mechanical measurement is the gram-meter representing the amount of energy required to raise one gram one meter, representing 424.5 calories. Some physicists make the unit the amount of heat required to raise one pound of water one degree C, so that one calorie in this case would be equal to 2.2 units and one thermal unit would be equal to .45 calories. The metric standard is more easily calculated and used.

Specific heat represents the amount of heat required to raise the temperature of a substance one degree C, the specific heat varying with different substances Water is usually taken as the standard unit. The specific heat of the animal body normally is .8 or .9, that is .8 of the amount of heat will be necessary to heat the same weight of the animal as of water. If we know the weight, specific heat and temperature of any substance we can calculate the total amount of heat in the substance. Multiplying the weight by the specific heat and the temperature gives us the total quantity of heat. In connection with the calorimeter it is easy to

calculate the change in temperature by multiplying the weight by the specific heat and the increase or decrease in the body temperature.

In the physiological calorimeters either water or air has been taken as the standard of measurement. In the water calorimeter there are double walls the outer space being filled with water. Within the vessel the animal is placed, the temperature of the water being noted at the beginning and end of the experiment. It is taken for granted that all the heat will will go to the water and none to the metal and that none of the heat gets through the external wall by any process of radiation. It is easy to calculate the amount of water that will be raised one degree C. by a certain amount of heat which will also raise the metal one degree C. This is called the water equivalent of the instrument. It is added to the water volume, the result being multiplied by the increase in temperature. The loss of heat by radiation can be removed by keeping the surrounding air constant and by regulating the temperature of the water in comparison with that of the air so that the gain and loss of the heat are balanced. The water calorimeter is not an exact instrument because of the impossibility of getting the exact water temperature on account of the difference in the heat at different water levels and because the water is difficult to heat by the heat given off from an animal.

In recent years the air calorimeter has replaced the water one. It really represents a thermometer with a wide radiation surface. The amount of heat required to raise the unit volume of air one degree C is very small compared with that of the water. A specific amount of heat raises the temperature of the air calorimeter more than in the case of a water instrument and the heat lost is in exact proportion to the rise in temperature. As the loss of heat in connection with the instrument comes to be equal to what is absorbed from the animal, the instrument becomes steady and in this way the heat production can be secured. In the case of the air instrument the heat loss is followed more carefully, for it is the heat emission or heat loss not the heat production that is measured. If the animal temperature has been unchanged the two quantities will be equal. If the animal temperature has fallen the heat produced will be represented by the quantity of heat in the instrument less the difference between the animal heat at the beginning and close of the experiment. The differential air calorimeter provides for the use of two instruments so that heat lost by conduction and radiation can be compensated for in the duplicate instrument. In the most recent form of it we find that the heat which is found in connection with the animal in one chamber is compensated for by the heat emitted from an H flame burning in a similar chamber. By estimating the H burned and knowing the oxidation value of the H we can estimate the number of calories produced by the H. This would represent the number of calories which the animal gives off. Associated with this calculation is the calculation of the amount of O taken in and CO_2 given off. The calorimeter has been applied to man in the case of parts of the body. Waller has devised a plan for the clinical examination of patients. He takes the deep and surface temperatures in different parts of the body, estimating the amount of water evaporated from the skin by the use of the hygrometer and noting the temperature of the room. By testing the thermometer in connection with calorimetric experiments it is easy to estimate the amount of heat given off.

In the calorimeter of Rosenthal the body or part of the body is put in a chamber surrounded by another chamber in which is air. In the instru-

ment are three concentric copper cylinders; in the inside one is the animal; the middle one represents an air space, the outer one providing an external casing to protect from radiation and conduction changes. There are attachments for supplying air after closing the chambers and also for the extraction of CO_2, Connected with the air chamber are a manometer and a thermometer. Reichert's instrument is the one that is in common use now. It consists of two concentric metallic cases fixed in such a way as to leave a space between the two of one and one-half inches, the space being filled with water. The external box is 15 inches high and wide and 18 inches long. At one end there is an opening 9 inches wide for admitting and removing the animal. At the top are four perforated holes, two for the entrance and removal of air, the entrance tube going down to the bottom of the inner chamber and the exit tube only to the top of it. In the third hole a thermometer is placed and in the fourth an instrument for mixing the water in the jacket. By estimating the calorimetric equivalent of the apparatus the amount of heat is found that is necessary to raise the apparatus one degree C. This is done by burning H inside the chamber. Each liter of H when oxidized gives a certain number of calories. The heat generated raises the temperature of the apparatus. When we know the amount of heat generated by burning H and the rise in the temperature we can easily calculate the calorimetric equivalent of the apparatus. When an animal is put into the inner box part of the heat given off is taken up by the instrument, part passes off in the air and another part through the H_2O excreted from the lungs and skin. To get accurate estimates therefore it is necessary to estimate the amount of heat imparted to the instrument, the amount absorbed in the air and the amount in connection with the water. The first can be calculated from the calorimetric equivalent of the apparatus. The second can be reckoned by measuring the air entering the instrument and the temperature of the entrance and exit air. The third can only be approximated by measuring samples of the air as it passes out and enters the instrument. Before putting in the animal the temperature of the animal is taken and after stirring the water the temperature of the chamber is taken and the temperature of the air entering and leaving. The amount of heat imparted to the instrument is calculated by multiplying the increase in temperature of the instrument by the calorimetric equivalent. The amount of heat given to the air is estimated from the volume of the air reduced to weight then multiplied by the specific heat of air at zero C. and the increase in temperature. The amount of heat lost in evaporation is calculated by comparing the vapor in the air leaving with that in the air entering the chamber. The total amount of heat given off would then be found by adding together these three quantities, heat imparted to the instrument, to the air and lost in vapor. To get the quantity of heat produced it is necessary to add to or substract from this total quantity the amount gained or lost by the animal while in the chamber. If the temperature is the same when taken out as when put in, the quantity lost represents the quanitty produced; if the temperature of the animal increases less is lost than produced; but if the temperature falls more is lost than produced.

By the use of these calorimetric methods the potential energy value of food can be estimated as well as the heat production and it can be measured by units of heat. It is important to remember that energy cannot be destroyed, it is simply changed in form. In changing its form

we have the transference from one unit to another. Hence Joule calculates one heat unit equal to 424.5 work units. In connection with an animal it is also important to know the relation of mass to surface area. Heat is generated in connection with the mass, it is lost from the surface. In animals mass and surface are not proportional, for the increase in the mass represents more than the corresponding increase in surface. Hence the physical law is, the mass increases as the cube, surface increases as the square. The result of this is that a small animal has a larger surface area than a larger animal; therefore a small animal loses heat more quickly than a large amimal. Hence it also produces more, because the chemical processes are more active in a small animal than in a larger one. This is true not only of heat but also of such excretions as urea, CO_2; of the food substances used and of the blood that circulates in a small as compared with the larger animal.

Besides the heat production that arises in connection with oxidation, there are certain physical processes that give rise to body heat. The kinetic energy associated with the internal body organs, as the heart, lungs, viscera, is transformed to heat; in addition to this we find the active energy arising in connection with the cartilages and muscles and the friction that is developed by the air in connection with respiratory activity, together with the electricity developed in connection with the muscles, nerves, and glands of the body, the electricity being changed into heat.

SECTION II. Body Temperature.

As we have seen a distinction is drawn between warm and cold blooded animals. This distinction, however, is not absolute. Even in the case of the warm blooded there is a close resemblance in certain conditions to the cold blooded as in the case of imperfectly developed or quite young animals, so that the difference is relative. In the case of the human subject and of most of the mammals the body temperature is pretty steady, varying normally within very slight limits. It is for this reason that man is classed among the homoiothermal animals whose temperature is constant. In a healthy individual the mean temperature varies only very slightly, the variation being found according to the part of the body, in which the temperature is taken. The temperature of the human subject varies normally about one half a degree. The temperature of the body organs is normally higher than the superficial body temperature. Bernard found the normal temperature of the lungs, muscles and brain 40.6. In the rectum it is about 37.2 degrees or 98.96F., at the axillae 36.9 or 98.45 F. and in the mouth 36.87 or 98.36 F., these figures representing average temperatures. It is usually stated that the normal temperature is 36.9 or 98.4 F. but this represents the temperature during activity, without taking any account of the night temperatures which are lower than the day temperatures. The mean temperature of the individual would be an average of the daily and nightly temperatures, the variation ranging in the mouth from 36.1 to 37.5, in the axillae from 36.1 to 38, in the rectum from 36.1 to 37.8 and in the urine from 36.1 to 38. degrees. In the case of the human subject in health the limits are about 36 to 38 or 36.25 to 37.5 axillae calculation, in the mouth the increase being about one fourth to one degree and in the rectum from one to two degrees higher. Above 37.8 it becomes a fever temperature and below 37 degrees a collapse temperature. In the case of children the tempera-

ture is higher and more liable to variation. After 40 years the average temperature is lower than in the normal adult. The variation found in the daily and nightly temperature represents a maximum from 9 a. m. to 6 or 8. p. m. and a minimum from 12 midnight to 6 a. m., at 6 the daily tide of life reaching the low water mark. There is a slight variation depending upon the character of the food. Exercise produces very slight change, compensating elements preserving the balance, the variation not exceeding usually one degree. In the case of animals the temperature is found to vary more than in the case of man, although the experiments have not been very carefully made in connection with average temperatures. In the horse it is found to be about 37.8, in the cow 38.7 and in the sheep 40.4, in the dog 38. 5, in the cat 38.7 and in the monkey 38.4. In most of the mammals the temperature taken in the rectum is above that of man. The temperature of birds is found to be two or three degrees above that of mammals. In observing temperatures for comparison it is essential to have the conditions as nearly similar as possible, so that no change may be due to changed conditions either in the animal or in the method of observation.

In regard to the cold blooded animals no definite variation can be laid down nor can they be said to differ from the warm blooded in any absolute points. In the case of bees the single bee seems to have little capacity individually of keeping up temperature, very rapidly becoming cold and powerless if exposed to the slightest cold. When bees are aggregated as in the hive the temperature is kept without very much variation. Hunter found the temperature of a hive 27 degrees in July when the temperature of the air was 12 and in December when the air was 1.7 the hive was 22.8 degrees. It has been found that the activity of bees increases the temperature above the air, while during winter when they are inactive the temperature falls to that of the air, varying very slightly. In most of the cold blooded animals the variation of the body temperature from the air temperature takes place at a mean temperature slightly above that of the surroundings. The average according to Schaefer above the atmosphere is about one degree varying in some to ten. In the case of some animals as the winter comes on they become inactive and assume a torpid condition. The body activity is lessened and the temperature falls to a point slightly above air temperature. These represent the hibernating animals, specimens of which are found amomg mammals, reptiles, amphibians, birds and possibly the fishes having no hibernation. In some cases food is stored up so that the animals awake up at periods to feed, while in others the fat accumulation provides for the nutrition of the body. Respiration is not destroyed but assumes the Cheyne-Stokes form with great irregularity. There is an absorption of O and an elimination of CO_2 varying considerably in different animals, the marmot being able to live in a CO_2 medium for hours without any perceptible change. Experiments have proved that of the O taken in a part of it, representing about one fifth, is stored up in the body, the balance being eliminated as CO^2. The heart force is greatly diminished, in the case of some animals the heart beat being entirely absent. The most reliable experiments indicate the fact that a large amount of CO_2 is found in the arterial and venous blood as compared with the active condition. The nervous system is much lessened in its irritability. The temperature becomes like that of the cold blooded animals, varying with the surroundings so that there is little power for preserving a constant temperature. As soon as the

hibernatino closes the temperature rises vary rapidly, more rapidly than in abnormal fevered conditions, this sudden rise in temperature being accompanied by quickened respiration, circulation and heart beat, the increase in the body activity being the cause of the rise in temperature. The cause of hibernation was at one time supposed to be extreme cold, but it is found that severe cold does not produce hibernation in an active animal some cases being recorded in which excessive cold aroused from the torpid condition the hibernating marmot. Some of the hibernating animals have been kept in a warm temperature during winter and yet they hibernated. In addition to the cold it is certain that the want of food is an important element, involving the inactivity of the internal organs. DuBois says that in hibernation we have a prolongation of the sleep condition produced by a kind of auto-toxication, the toxic in this case being CO_2. He claims that in the case of hibernation the CO_2 is found to excess in the blood especially in connection with the brain.

These cases of hibernation indicate some of the means for preserving body heat in normal conditions and also mark some of the conclusions that may be reached in regard to the limitations of body temperature that are compatible with living conditions. We have seen that the variation of body temperature in man is slight, not normally above two degrees. This however may be considerably modified in pathological conditions. Exposure to cold, particularly in the case of intoxicated persons does not seem to affect life conditions, even if the exposure is severe and long continued. It has been found that the fall of the body temperature to 24 degrees on account of such exposure under these conditions of intoxication has not proved fatal. It is true that unconsciousness was induced but proper treatment resulted in the restoration of consciousness. Lowenhardt found the body temperature as low as 23 degrees in the case of an insane person and in others from 25 to 29. In these cases the persons were of peculiar animal habits going about undressed and without taking much food. In the majority of cases when the temperatnre is reduced to from 25 to 32 death results either shortly after the fall in temperature or after the lapse of some time. Attempts have been made artificially to reduce the temperature of some animals, the result being that in cases where the temperature is cooled to 18 degrees death results; in the case of rabbits it is found that artificial cooling to 18 degrees produces paralysis and an almost inperceptible heart beat, the respiration being either very slow or very rapid, the muscles and nerves preserving their irritability. In cases of sudden and great changes below body temperature the metabolic processes are lowered heat production being stagnant. The rapidity of the change has a great deal to do with the fatal results because if the change took place gradually so as to accustom the body to the lowered metabolism fatal results might be avoided. The lessened metabolism if continued however affects the brain thereby influencing consciousness and the controlling power of heat production, resulting in a lethargic state passing into death.

In regard to the limit of variation above body temperature there are some clearly established cases of hyperpyrexia in which the temperature has been found as high as 46.1 or 114.98 F in case of scarlet fever, 44.75 or 112.55 F in cases of tetanus; but all these cases have been fatal. Levick and Donkin record cases in which at a temperature varying from 44 to 46 degrees recovery took place and in some cases of rheumatic fever a temperature of 43.55 recovered. According to Bernard whose experi-

[illegible] the condition may be [illegible]
[illegible].

ments upon birds and rabbits led him to conclude that the limit of life was placed at 45 degrees in rabbits and 51 in birds, he concluded that the cause of death in pyrexia conditions was heart stoppage due to the excessive heat, producing muscular rigidity. From this it is concluded by analogy that in the case of a man the highest limit of body temperature may be set at 46 degrees, 47 representing a point at which death results rapidly, this being due as has been suggested to proteid coagulation in connection with the muscles resulting in the rigor mortis state. The mechanism of the body cannot stand too much heat. Hence to raise the the temperature 6 or 7 degrees usually entails death. The producing cause of death in these cases may be taken as the increased metabolic activity in connection with the tissues, producing a rapid destruction of the substance. Overmuch heat produces dyspnoea and this condition very soon exhausts the center of respiration. The effects upon the heart are noticeable in connection with the quickened beat, the stroke being enfeebled and irregular. In addition the nervous system is subjected to rapid changes resulting in the loss of consciousness and the loss of control of the tissues of the body, so that a general disorder results in the body. Sometimes death results from loss of heart action, sometimes from the cessation of respiratory action and more commonly from a general brain coma. Where the temperature is raised excessively it reaches the point represented by muscle coagulation, namely 50 degrees. In such a case the muscle rigidity produces death. Thus the limits of life temperature so far as the body is concerned in the human subject may be placed at from 18 or 64.4 F to 46 or 114.8 F.

In normal conditions there seems to be the power of preserving a constant temperature. This is found even in the cold blooded animals, as in the case of the female python compared with the male during the period of incubation. In the warm blooded animals this is more marked, growing with the development of the animal. In the embryo chicken we find that the temperature is liable to change as in the cold blooded animals following the surroundings; towards the latter stages of the embryonic life the tendency to preserve normal temperature is developed and after hatching the regulation of temperature becomes established in the body. Edwards says that young mammals are either warm blooded or cold blooded as they are able or unable to preserve the temperature of the body alone; for example in the case of feathered and furred animals as compared with those without feathers or fur. In other words the inability to preserve the body temperature constant depends only to a slight extent upon heat loss, depending primarily upon heat production and the means of preserving its continued production when exposed to a cold medium. In connection with infants and immature or weakly children we find the inability to preserve the balance of the temperature; if the weakness or immaturity continues the power of preserving body temperature is limited, whereas if in development the child is normal, when the adult stage is reached the perfect power of maintaining body temperature is attained. The power of regulating normally the body temperature is thus dependent upon development. This takes place largely in connection with the nervous system as the nervous system gains control over the muscles and the circulation of the blood throughout the body. The division of the spinal cord or the administration of curari or chloral deprives the human subject of the power of regulating the body temperature, becoming subject to the variations of the surrounings as in cold

blooded animals. That the nervous and muscular systems form the basis of this power of regulation is evident from the hibernating animals whose muscles and nerves lose to a large extent their tone during hibernation, the tone being resumed after hibernation, when exercise is resumed and the excessive amount of CO_2 is discharged from the system. The maintenance of the normal control of the body temperature depends therefore upon the normal condition of the muscles and nerves. The body is producing and losing heat during life and yet the body temperature is preserved constant although the surroundings vary, indicating that there is a mechanism for preserving the balance. It is only when there are changes either in the heat production or loss that the temperature rises or falls. It is not necessary that if heat production is increased the temperature must rise as the loss may be correspondingly increased so that temperature equilibrium may be preserved when heat production and loss are normal and when they are increased or decreased correspondingly. If however heat production is normal and heat loss abnormal or vice-versa, there is a change of body temperature. It has been supposed that body temperature depends upon the changes in heat production. This however is incorrect. In pyrexia the rise in temperature is generally due to increased heat production. It may also be due to diminished heat loss. The change in body temperature simply indicates that the balance of heat production and heat loss is interfered with.

Experiments have proved that injuries in the brain, particularly produced by puncture, will increase the body temperature, this increase being marked by increased metabolism indicated by an increase of O consumption and CO_2 excretion. This forms the basis of the existence of a nervous heat center in the brain. The pyrexia conditions represent an increase varying from 39 to 44 degrees, but these temperatures cannot last long without affecting the body. Sometimes the increase in temperature arises in connection with some local disturbance as in specific diseases or it may arise in connection with some germ or foreign substance. In these fevered conditions there is an increase in the O consumption and CO_2 production, indicating tissue changes and also increased urea production, ndicating metabolism in connection with the nitrogenous food elements. These conditions involve waste. In some diseased conditions there is a fall of temperature most generally due to decreased metabolism and lessened heat production. This is indicated by the fact that in case of starvation there is a marked temperature fall, becoming more marked as death approaches, the lower temperature increasing the rapidity of the approach of death. To preserve the temperature equilibrium and restore it when disturbed involves the exercise of a special heat mechanism which we will discuss later.

SECTION III. Temperature of the Different Parts of the Body.

The quantities of heat produced and lost in the different parts of the body vary. The circulation of the blood tends to equilibrate the temperature of the different parts, but this is not accomplished absolutely, so that there is a varying internal temperature. As the results in connection with the thermometer vary in different conditions great care must be taken to make accurate observations. The rectum affords a most convenient means of estimating the internal temperature of that part of the body.

The same is true of the vagina, the uterus and the bladder. To estimate the general internal temperature it is convenient to place the thermometer in the urine stream as it passes from the urethra, although this method does not give absolute accuracy as heat is lost by radiation in connection with the urine flow. At the axillae is found one of the most easily accessible and generally constant places for taking the tempearture, provided the axillae are kept closed so as to prevent the evaporation of heat. The mouth has also been commonly chosen as a suitable part for estimating temperature but in connection with the mouth there is liable to be loss of heat on account of the action of the air in inspiration and expiration. This makes the mouth subject to much local variation in temperature. Sufficient time must be allowed in placing the thermometer in any of these positions to allow of its becoming steady; three or four minutes in the rectum, vagina or in connection with the uterus and bladder; seven or eight minutes in the mouth and nine or 10 in the axillae. The rectal temperature represents about .3 or .4 above that of the mouth or axillae, sometimes however the mouth is found to represent a higher temperature as is the case after eating, probably due to increased exercise of the deglutition and buccal muscles and the increased blood flow. Severe exercise has been found to lower considerably the mouth temperature and to raise the axillae temperature, the respiratory activity cooling the mouth and warming the axillae by an increased circulation of the blood. In order to estimate the highest internal temperature an out-flow thermometer is swallowed so that when it is excreted and placed in water the water can be slowly heated to the point of out-flow. This will represent the highest body temperature internally. In the case of a dog it has been found to be 39.2 degrees, while the rectal temperature was found to be 37.9 degrees.

Body heat is produced chiefly in connection with oxidation of the muscles and glands, while heat is lost chiefly from the external surface of the body. This produces a gradually increasing temperature from the skin surface to the interior of the body and the internal organs. The difficulty of representing the internal temperature is found in the fact of heat radiation and conduction. There is great difference in the observed temperatures of the different parts of the body chiefly due, aside from errors of observation, to the variation in the blood circulation in different parts at different periods of time. Some have stated that the mouth, axillae and rectal temperatures are the same. The majority of the observations, however, place the axillae temperature lower or higher than the mouth and the rectal temperature higher than the axillae and mouth from .3 to .6 degrees. The general conclusion may be taken as settled that the rectal temperature is highest, whereas the mouth and axillae temperatures vary considerably at different times so that they may be regarded as about equal. In the case of the dog experiments have placed the temperatures as follows: rectum 38, liver 38.2, right ventricle, stomach and abdominal aorta 38.3, portal vein 38.6 to 40 and hepatic vein 40.6. In the case of lambs just dead the rectum temperature is 40 to 41, brain 40 to 41, right ventricle 40 to 41, left ventricle 41 to 41.7, liver and lungs 41.5.

Much discussion has taken place in regard to the blood temperature. This arose from the ancient physiological idea that the heart was the producing cause of the body temperature. Lavoisier experimented in this connection with the conclusion that the heat production took place in

the passage of the blood through the lungs and other internal body organs. The conclusion of Berthelot is that heat is produced in the passage through the lungs in the union of O and hæmoglobin. In regard to the variation between the arterial and venous blood Bernard after comparing and classifying the experiments of his predecessors and himself concluded that where in the living animals he introduced the thermometer into the blood through the vessels in the neck the blood of the left ventricle is .1 to .2 degrees cooler than that of the right ventricle. The older experiments he says were incorrect because of the opening and exposure of the chest and thoracic organs, the right ventricle cooling more rapidly than the left on account of its thin walls. Heidenhain without opening the thoracic cavity inserted thermo-electric needles into the left and right ventricles through the carotid artery and the jugular vein. in the carotid it is from .3 to 2 degrees higher than in the jugular vein. In all the experiments except one he found the left side of the heart cooler than the right, the blood being cooled in passing through the lungs during respiration. In order to test the effect of air upon the temperature of the blood he used hot air at 40 degrees and cold air at 17 degrees for artificial respiration with the result that the difference between the temperature of the arterial and venous blood remained unchanged. Thus the left ventricle is cooler than the right, the walls of the latter being closer to the liver and the abdominal viscera, while the walls of the former are adjacent to the lungs, so that the difference depends upon proximity to warmer and cooler body organs. Others say the difference is due to the more active oxidation processes in arterial,blood heat being found in connection with the oxy-hæmoglobin formation. The superficial skin temperature shows sonsiderable variations in different parts of the body surface, the variations depending upon external surroundings including temperature, clothing, blood supply and free or retarded evaporation. The averge blood temperature is about 39 degrees, the warmest blood being found in the hepatic vein, and the coldest at the exposed parts of the body, ears, nose, etc. being as low as 26 degrees. In the circulation of the arterial and venous blood away from the heart the venous blood in connection with the internal viscera is warmer than the arterial blood, but in the peripheral regions the arterial blood is warmer. The blood in the arteties is usually warmer than that in corresponding veins, the crural artery being from .75 to one degree higher than the corresponding vein. The hepatic vein is from one to two degrees higher than the portal vein during digestion and .6 higher than during the intervals of digestion. This is due to the superficial position of the veins and to the fact that the superficial veins are constantly giving off heat. The blood that is warmest is that of the hepatic vein chiefly on account of the activity of the liver in the metabolic and secretory processes and the closely protected position of the liver. The blood as it leaves the muscle during rest is .2 and during activity .7 degrees warmer than that entering the muscle.

The ordinary thermometer is not satisfactory in measuring surface temperature because there is a loss and gain of heat from exposure and contact. In order to get satisfactory results the thermo-electric method is adopted. Some object to the resistance thermometer on account of the complicated apparatus and also on account of the fact that the slightest animal motion affects the galvanometer. For this reason most of the experiments have been made with the flat mercurial thermometer

covered with a non-conductor. The thermo-electric method enables us to find out the temperature with accuracy and rapidity. The thermo-electric galvanometer consists of a circular magnet hanging from a silk thread to which is attached a small mirror. There is a fixed bar magnet close to the circular one, the N poles of both magnets pointing in the same direction Around the circular magnet is coiled a thick copper wire the ends of the wire being soldered to two thermo-elements consisting each of two metals, the two free ends being connected so that the entire copper wire and elements form a complete circuit. A horizontal scale is placed three meters away from the mirror the scale resting on a telescope pointing towards the mirror so that accurate observations can be made. The two thermo-electric needles are then placed in the tissues or one in the tissue substance and another in a bath of constant temperature, so that the difference between the surface temperature and the constant heat source can be obtained. In this way by connecting these needles with the circuit an exact estimate can be formed of the temperature. In connection with these experiments the temperature of different parts has been found, Kunkel concluding that the temperature of the superficial skin is almost constant so that body temperature would be affected only very slightly by skin temperature. The other temperatures are, forehead and cheek, arm, sternum, right iliac fossa 34.1 to 34.4, lobe of the ear 28.8, back of the hand 32.5 to 33.2, palm of the hand when open 34.4 to 34,8, when closed 34.8 to 35, wrist 33, forearm 33.7 to 34, over the heart 34.6, back and thigh 34.2 to 34.5. Exposure to cold reduced the temperatures slightly and muscular exercise of the arm increased the temperature of the arm. The highest temperature found on the surface of the skin was on the face, 35.6. The forehead and the parietal temperature is higher than the occipital. The superficial temperature on the right side of the head is colder than on the left. The superficial temperature is lower away from the arteries than over the arteries; it is lower over organs of the body that are less active.

In connection with the stomach the temperature is lowered during digestion. In the celebrated Saint Martin case Beaumont says that by introducing the thermometer into the stomach through the gastric fistula the temperature stood at 37.8. The heat of the organs or tissues depends upon the extent of the tissue metabolism, the amount of blood and the protective or exposed position of the organ or tissue. According to Heidenhain the warmest part of the body is the cerebrum, but according to Bernard the liver is the warmest organ, then following the brain, the glands, the muscles and the lungs. As the different parts of the body vary in temperature there must be a continuous transmission of heat from the warmer parts to the colder in order to maintain body equilibrium. The distribution of heat in this way takes place both by radiation and by the circulation of the blood and lymph. With these complete means of heat transmission however body heat equilibrium is not evenly distributed, the internal being warmer than the external and the more active warmer than the less active internal organs. It is in the muscles that the largest amount of heat is liberated resulting from the chemical changes taking place in these. In connection with the nerve centers in the liver and other fluids of the body there is also a large heat production.

SECTION IV. Influences That Affect the Body Temperature.

The mean body temperature is subjected to a great number of variations these depending upon certain conditions associated with day and night, age, constitution, diet, etc.

1. THERE IS A DIURNAL VARIATION.—The temperature of the body is subject to regular daily variations from one to two degrees, the maximum from five to eight p. m. and the minimum from there to six a. m. These variations are marked by certain rhythmical changes taking place, these rhythmic changes being unaffected or only slightly by lack of food. These diurnal variations correspond with the pulse rate. At the minimum of pulse and body temperature there is the tendency on the part of the sick to become weaker and to yield up life. The temperature rises in the morning and in the afternoon and it goes down in the evening and early in the morning. The observations indicate a very marked difference in different individuals. On tabulating the results of observations the maximum variation is found to fluctuate much more than the minimum. This arises chiefly from the fact that before reaching the maximum there is a variation of rise and fall in the temperature. This variation in the approach to the maximum cannot be explained. Variations in the daily temperature may be explained largely on the basis of difference in meals and in the time of meals, as well as the age and condition of the body. Such variations so far as investigations have gone seem to exist among all races of people to a greater or less degree. In regard to the producing causes of these variations the chief are associated with diet and muscular excercise. The period of body activity is during the day, and so much is this true that it has been found in the case of those working during the night that the variations are reversed, the minimum being found in the evening and the maximum in the morning. In the case of wakefulness during the night without active manual exercise it has been found that the same effect results to a lesser degree. Mosso experimented in connection with normal workers who rested during the night and with those who slept during the day working during the night. At first there was no marked change in the variation of the maximum and minimum temperatures but as habit began to accustom the individual to the inverted order the variations began to follow the order of work. The main cause then is the exercise and work of the individual. In addition to this body temperature is materially affected by the external temperature of the surroundings, the rise and fall following to a greater or less extent the rise and fall in external temperature. Habit has a decided influence upon temperature, so strong is it that an incidental change in the food or the time of meals, or even by fasting, or an incidental exchange of sleep and wakefulness does not interfere with the variatiens in temperature. So strongly does habit influence these periods of temperature rise and fall that the digestive and metabolic processes become fixed habits associated with the body, these habits being difficult to change. Even in the case of a person used to work during the day if he suspends this work and rests for a day there is little if any variation from the normal temperature. It is claimed by some that the same diurnal variations are found among different animals, for example, in the horse, the minimum being in the morning from about 4 a. m., and the maximum in the evening from about 6 p. m. The same thing is said to be true of

the cow and cat. This variation then seems to be found associated with most animals depending upon the variation in the activity of the tissues and organs of the body, representing the activity of such organs as the heart, the lungs, the liver and the muscles in general.

2. Age and Sex.—The temperature of the newly born animal is generally higher than that of its parent, but as we said it is much less constant being liable to very great variation; so much so is this that in the case of newly born animals if removed from their warm surroundings and left to themselves they lose heat quickly till a point is reached slightly above the atmosphere. Edwards found that this is not true however of all newly born animals. In the case of young guinea pigs they are able to preserve their temperature if not suddenly exposed to a very low temperature. Hence he says there are among the new-born animals those that are warm bloooded and others that are cold blooded. The former class of animals is entirely dependent upon their surroundings having no covering, being born blind, the foromen ovale remaining open a few days and being in a helpless condition; whereas the latter at birth can see, have a covering naturally for the skin and manifest considerable activity. In the case of premature birth it is found that animal heat varies more considerably. While unable to explain the cause of the difference, Edwards showed that the difference was not due to the comparative size of the superficial body surface, or even to the absence of a covering from the skin, as he proved that in the case of some birds the body temperature can be maintained, even in the absence of feathers. In the case of the human infant many experiments and observations have been made. The surface body area and skin evaporation of heat account for only a small part of the heat loss. Experiments in connection with hot and cold baths led Raudnitz to conclude that the difference depended upon the perfect or imperfect development of the power of regulating the body temperature. In utero the foetal temperature is slightly above the maternal uterus. At the period of birth the normal rectal temperature is about 37.8 degrees, about .1 to .3 of a degree above the maternal vagina. Very soon the temperature falls almost one degree within a few hours, after which it gradually rises again to about 37.46 and remains comparatively constant about 37.6, although the normal variations are much more irregular in children than in adults, the variations being altered by bathing, crying, sleeping etc. From the period of birth to the change of life represented by puberty there is a fall of about .2, from puberty to about 30 years of age another fall of .2 takes place, about 37.1 being the adult temperature. After 35 the temperature begins again to rise, according to Wunderlich, gradually approaching, as senility advances during the second childhood, the infantile temperature again. It is generally agreed that after 45 it goes down till about 65 when it reaches 36.8 and then gradually advances till about 80 it is 37.4 degrees. Most physiologists agree that in old age the temperature is slightly higher than during the adult condition, although Charcot says that he rarely found in old people a temperature above that of the adult. This however is due partly to the fact that Charcot measured the temperature at the axillae where on account of the debilitated circulation of the blood the temperature is lower than in the rectum. This has been confirmed by many recent experiments in which the rectal temperature represented a much higher temperature than that of the axillae in old people. In the case of sex it is claimed by some that the male has a slightly higher temperature than the female, although the difference so

far as noted has been but slight. Wunderlich states that very little difference is noticeable between the sexes; the females have a slightly higher temperature but this as he states is due to the fact that their temperature is more subject to variation. Davy whose conclusions are the opposite of this rests his conclusions upon only a few examples. Recent observations upon animals seem to indicate that the female is slightly in advance of the male temperature, not howeeer exceeding half a degree. Normally, menstruation and pregnancy do not seem to affect the temperature of healthy persons. During parturition there is a slight rise in temperature but this is accompanied by variations, indicating fall and rise of temperature followed by a fall in temperature after parturition. Associated with age and sex are variations due to individual peculiarities. It has been remarked that individuals represent varying temperatures; the variations depending upon individual eccentricity, the variation being from 36.25 to 37.5, temperament and disposition as well as the individual organism accounting for these individual variations. Connected with the individuals variationsare racial variations. Those who inhabit tropical countries have a slightly higher temperature than those of cold or temperate regions, the difference being due mainly to climat variations. That this is so has been proved by comparison of the temperatures of residents in tropical regions who have formerly inhabited the temperate and colder climates, with the result that there is an increase during the tropical residence of .6 to .7 of a degree.

3. Psychic Influence.—Psychic influence representing mental activity has an effect upon body temperature both generally and locally in the brain. Davy experimenting upon himself found that mental effort varied his temperature .25 and 1 degree in England and in tropical regions. This rise in temperature was produced by excited and sustained attention. This observation has been disputed by Allbutt, although more recent experiments have proved the truth of Davy's statement. The emotions as well as the passions increase body temperature, while fear or mental trouble produce a lowering of temperature. In the case of trephining a skull, it was found by using the thermometer that mental exercise increased the temperature .2 or .3 of a degree.

Mosso has claimed that great mental activity produces intense heat increasing the brain temperature considerably above the axillae and rectal temperatures. In a dog subjected to curari it has been found that by the use of cocaine the brain temperature can be raised three or four degrees. Lombard claims that the effect of mental action is to increase the temperature of the occipital brain region. Mosso claims that this was due to the increase of cell activity. As we have seen however there is an increase circulation in definite brain areas and to this is due in connection with the vascular brain variation in all probability the increased temperature. It is claimed that the venous blood in the brain is less venous in character than the normal venous blood of the body, indicating the slight metabolic activity of the brain. The brain temperature does not seem to vary much from the blood temperature as it circulates through the brain. There are constant changes in the circulation of the blood through the brain and these are associated with definite vascular variations, so that the heat arises in all probability from the blood and not from the substance of the nervous tissue cells in the brain. In the case of sleep we find the regularity of circulation and of the vascular variations of the brain. This represents a condition of relative inactivity

and rest so that the body temperature falls during the night and in the early morning. It is claimed that sleep lowers the temperature, cases being cited in which during the day persons who have slept have lost almost half a degree in body temperature. This it is claimed however by others is due not to sleep but to a resting condition of the body. Inactivity or rest results in a fall of temperature and this seems to be increased by sleep especially if the habit becomes general so that sleep may be said to lessen the body temperature slightly. This of course will depend upon the psychic condition, for if it represents a disturbed mental condition, such as we find in dreams, then the fall in temperature may not accompany sleep.

4. Food and Exercise.—Food produces an increase in body temperature. This is true of the meals of the morning and midday and to a certain extent of the evening meals as in this last case it puts off the fall in temperature to a later period of night. The maximal effect is not produced at once in connection with the meal but when the process of digestion becomes active an hour or two after taking a meal. If cold water is taken along with the food the effect is to keep the temperature from rising. Some physiologists claim that the food furnishes the principal cause of the variation in the body temperature, claiming that in the case of animals deprived of food during the day and fed during the night the fall in temperature in early morning gives place to a rise in temperature. This, however, has been denied by others who hold that the rise and fall of temperature represent periodic variations in the temperature and that while slight modifications may take place the variations can not be great. Bernard believes that body temperature is increased from the internal organs during digestion, for example in the liver there is an increase in temperature while digestion is active, representing a variation in the beginning of digestion and when digestion is very active of from two degrees in the portal vein to three degrees in the hepatic vein. This represents an increase of half a degree in the heat of the blood on the right side of the heart. During the deprivation of food there is a gradual fall of temperature, the diurnal variation becoming more irregular, until just before death takes place when there is a sudden and great fall in temperature. This fact observed uniformly among animals seems to be disproved in the celebrated case of Dr. Tanner. After fasting 30 days there was no fall of temperature, on the 30th day the temperature being 37 degrees in the mouth. This is explained by the fact that water was taken freely continuing the metabolic activity. It seems certain that active digestion increases the internal temperature from .2 to .3 degrees at least slightly and this increase if distributed over the body will at least slightly increase the body temperature. This, however, it is claimed by some is due rather to the activity in the muscular exercise of the internal body organs than to the food. An insufficient diet results in a fall of temperature while an increased diet especially if rich in fats and carbohydrates increases the tamperature. Everything that tends to increase metabolism seems to favor an increase of temperature, for example, brain, gland, muscle, activity all produce more heat.

We know that muscular activity increases the production of heat. At the same time there is a large amount of heat lost and this produces equalization of temperature at least gradually. The influence therefore of muscular exercise depends upon the power of regulation and the power of compensating for heat gained by heat loss. Davy has experimented

freely upon himself in this respect in connection with active work indicating an increase varying from .3 to one degree. Even in the case of work done when the external surroundings are cold there is found to be a slight increase in body temperature. Several experiments have tested the effect of mountain climbing attesting the truth of this statement, the variations being found from .85 to 1.45 degrees. Opposite conclusions are reached by other experiments particularly in the ascent of Mt. Blanc during which the temperature gradually fell, Lortet explaining the fall by the fact that the heat which should have gone to maintain body temperature was expended in motion and locomotion This is accounted for by the fact, however, that the fall in temperature was marked at the mouth where on account of the free breathing of the cold mountain breeze the temperature was really below the body temperature, a short time of rest restoring the body temperature to its normal. Following this the experiment was tested by two experimenters who ascended Mt. Jura with the result that by testing the rectal temperature a decided rise in temperature was noticed. This seems to be an established conclusion in regard to muscular exercise, that an increase is noticed even on very slight muscular exertion. The heat of the body thus depends upon the variation in the warmth of the blood, depending upon the active circulation and location of the blood. This in turn depends upon chemical changes. The tissue changes are all chemical changes, these resulting in the setting free of heat. The amount of heat liberated can be estimated as the oxidation process always produces a certain amount of heat. All the chemical changes of the body produce heat in some form, the carbonic oxidation resulting in the production of CO_2 being the chief source. This is proved by the fact that the variation in temperature depends on the amount of CO_2 excreted. Body heat depends on the mechanical activity, also, muscle movements, locomotion, friction and general body activity producing heat. The muscles represent the organ in which the greatest amount of heat is produced. This is proved by the fact that the blood leaving the muscle is warmer than that entering it and also by the active changes taking place in the muscle itself. The nervous system, especially the centers, and the various glands of the body are also heat generators. The increase of respiratory activity in connection with bodily or mental exercise and the digestion of food marks the generation of heat and therefore a rise in body temperature. Where O absorption and CO_2 exhalation are decreased there is a fall in body temperature. In the case of muscular exercise the rise in temperature takes place in connection with the muscle substance. By introducing a thermo-electric needle into the biceps muscle in the case of a man who had been actively working for a short time there was a decided rise of 2 degrees in temperature. In the case of a frog's muscle even after the removal from the body there was an O absorption and CO_2 excretion and a rise in temperature following artificial stimulation to contraction.

5 INFLUENCE OF THE HEART BEAT AND THE BLOOD.- There is a close connection between the heart beat and the body temperature. The same relation has been observed between the body temperature and the daily pulse variations, indicating the close relation of the heart rhythm and the blood circulation in connection with the temperature of the body. It has been pointed out by Aiken that for every increase of one degree F in excess of the normal temperature there is an increase of 10 heart beats per minute. Other observations have indicated that with the increase of

the temperature about 37 degrees the pulse rate increase is not constant, varying from 8 to 28 beats per minute of an increase. Some recent experiments have indicated that with the decrease of body temperature there may be a rise in the pulsation rate. The result is that no principle can be laid down in regard to the relation of the heart beat and the temperature. The blood has a more definite influence upon the temperature, particularly in the case of parts of the body. The heat of different parts of the body depends upon the amount of blood and also the rapidity of its circulation through that part of the body. This is well illustrated in the case of a cold compared with a warm hand. For example in the case of increasing or diminishing the blood supply to the arm by simply lowering or raising the arm there is an effect in the arm heat. It has been observed that by keeping the arm in an elevated position there is a tendency to lower the temperature of the hand, the fall in temperature depending on the length of time during which the arm is kept elevated. By compressing the axillary artery the temperature of the biceps muscle falls considerably. Similarly the ligature of the crural artery produces a fall in temperature. In the external parts of the body more heat is given off than is produced so that if blood flows slowly to the external parts of the body the process of cooling is rapid and if the new blood passes quickly to the exterior the cooling is replaced by a rise in temperature. To increase the blood flow therefore increases the external temperature by bringing it closer to the internal and vice versa. In the internal parts of the body a large amount of heat is produced and given off to the blood. If therefore the blood flow is increased the temperature falls and if it is lessened the blood temperature rises. By compressing the veins of the arm the temperature of the hand has been found to fall as much as .45 of a degree and by compressing the brachial artery it has been found to fall as much as two degrees. To increase the blood supply to the skin surface tends to increase the temperature superficially while decreasing it internally. These facts seem to indicate that the blood supply has an important relation to the body temperature. These changes take place largely if not altogether in connection with the variations produced in the blood supply by the nervous system. Animal heat is a necessary element in body nutrition, depending upon the circulation of the blood. In the case of dividing the vaso-motor nerves the heat production is lessened on account of the interference with the supply of blood. Whatever increases the blood supply to a part of the body raises the temperature and whatever lessens the blood supply to any part of the body diminishes the heat. After a large vessel is ligatured the parts supplied with blood become cool and it is difficult to preserve body temperature in that region until by anastomosis the blood comes to freely circulate again. The nervous influence upon the blood supply arises chiefly reflexly in connection with the nerve centers, four heat centers having been localized and associated with the increase of body temperature. It is found for example that in the case of puncturing any one of these four regions the temperature increases continuing for a length of time subject to variation. These four regions are (1) Anterior to and beneath the corpus striatum; (2) the middle portion of the corpora striata and the adjoining parts beneath; (3) in the region between the optic thalamus and the corpus striatum; and (4) on the anterior inner side of the optic thalamus. In regard to these centers and their effect upon the heat production we will have something to say when we come to the heat

mechanism. Disturbances of the nervous system modify temperature, interfering with the regulative power of the body. Irritation of the nerve centers and of some of the nerves produces changes in body temperature some parts of the brain cortex being very sensitive, particularly the pons varolli, the corpora striata and the medullary bulb.

6. THE INFLUENCE OF EXTERNAL TEMPERATURE.—In the case of man as he belongs to the warm blooded animals his body temperature is not influenced very materially by the temperature of the surroundings, his body temperature being constant with very slight changes. Observations ~~have~~ been made in the case of voyagers in tropical and frigid regions. Davy made personal observations upon himself and seven fellow travelers in the prime of life on a voyage from England to the Island of Ceylon. He found that when the air temperature was 15 degrees the mouth temperature registered 36.9 and when the air temperature rose to 26 the mouth temperature was 37.32. He concluded from these observations that in passing from a temperate region to a tropical country the body temperature was increased; by analogy he argued that the body temperature of tropical residents is higher than those residing in temperate regions. Various other experiments have shown that there is an increase in the tropical temperature as compared with the temperate and it seems to be generally admitted that there is an increase in the average body temperature in the torrid zone, although the increase is not large. It does not exceed one degree. Crombie found that in moving from England to India there was an increase in his body temperature as estimated by the mouth but that the increase became less marked after residing in India for some time, the average increase being .2 of a degree. In regard to the effect of change of external temperature observations have been made recently by a number of investigators indicating that in the torrid zone there is always a slight increase in temperature. Neuhauss estimates it from the rectum and finds there is also an increase in the pulse rate varying from five to 10 beats.

In connection with the variation depending upon external temperature it is important to consider the effect of variations in the seasons within the same region. There is found to be very little variation depending upon the seasons. During the summer the body temperature is from .1 to .4 degrees higher than during the winter. In warmer climates it is .6 degrees higher than in the colder climates, this being due to the difference in climate in the different countries and not to racial differences. There is a slightly lower temperature in the mouth during winter than during summer, this being due possibly to an increased heat evaporation in connection with the skin. In the tropical regions where the extremes of summer and winter do not exist the changes due to change of season are imperceptible. In opposition to the generally adopted theory Bosanquet says that the highest temperature he observed in the rectum was during the winter and spring months when the external temperature was lowest, these observations being continued upon himself daily during the entire course of the year for three successive years. The general conclusion seems to be that in warm weather there is a slightly higher temperature in connection with the body than in cold weather. In regard to the inflence of extreme heat it is found that the body can preserve its temperature by means of heat evaporation in connection with the sweat so as to maintain the normal temperature. It has been observed that the body temperature varies most in cases of moisture in the air, the moist air

when heated having the effect of increasing the temperature of the body above the normal, whereas exposure to the dry air does not appreciably affect the body temperature. A large number of experiments are on record in regard to the effect of extreme heat upon the body temperature. If the surface of the body is well protected the body can bear a heat above boiling point for a few minutes, the body temperature being only slightly raised. In experiments under these conditions the body temperature was raised to 39 degrees, when subjected to a temperature of over 100 degrees C. It has been found that a dog, cat and sparrow all die when placed in hot air of 63 degrees, the dog and cat surviving about 30 minutes. When a dog is placed in an air of 36 there is found to be a quickened respiration without any fatal results; if the temperature is raised to 42 respiration becomes quicker and there is a feeling of pain associated with the action of heat upon the body; while a temperature of 45 quickly proves fatal, death being associated in this case with convulsions. Bernard compared experimentally the effect of dry and moist air, in the moist hot air death taking place very quickly, almost identical with imemersion in hot water. It has been stated by some that on raising the temperature of the air there is at first a slight decrease in the rectal temperature, soon followed by an increase, death resulting before the internal body temperature reached 45. Associated with death in these circumstances were increased respiration and pulse, spasms, loss of consciousness accompanied by restless movements, the pulse entirely disappearing before death, possibly on account of fibrillar contraction of the cardiac muscle. A post mortem examination indicated the presence of well marked congestion in the lungs and brain, non-irritability of the muscles and the rapid coming on of muscle rigidity. These correspond with the observed symptoms, conditions and post mortem signs in case of death by sunstroke. It has been found that extreme cold does not affect materially the temperature as in the frigid regions the body temperature is about the same as that of animals in the temperate regions. This is partially due to the additional protection which is furnished the body so as to keep the body warm. Currie immersed an individual in very cold water reducing the body temperature 8.25 degrees but he could not reduce it below 28.33 C. Even this fall only lasted a few minutes, the temperature of the body quickly resuming its normal. In the observations of Parry and Black we find that there are variations in temperature among animals such the arctic fox, wolf and fowl of from 38 to 40 degrees in an external medium of from 1 to 35 degrees below zero. The limit of life in the case of these animals seems to be the freezing of the water medium in which they live or the freezing of the fluids within the body, indicating the inability of the body to regulate and maintain the body temperature. It has been found that fishes and frogs go asleep in the ice when frozen and revive when they are thawed out of the ice, indicating the power of resistance to extreme cold in the case of some animals. The prolonged exposure therefore to either very great heat or cold is dangerous to life, for example exposure to 100 degrees C may produce a difference of 2 or 3 degrees in body temperature in a few minutes. The normal temperature does not vary more than 2 or 3 degrees under exposure to extreme cold or heat, so that the limits of life temperature have been placed at 28.33 as the minimum and 41.65 as the maximum.

7. THE INFLUENCE OF DRUGS.—The use of alcohol produces a decrease in body temperature, there being a temporary increased warmth produc-

ed by the increasing blood supply to the superficial region of the body and the increased action on the part of the sweat glands. The effect of alcohol is both negative and positive, negative because it temporarily produces a flushing of the cutaneous surface without increasing the heat of the tissues; positive because it produces a loss of heat by dilatation of the superficial skin vessels, stimulating the superficial circulation and promoting the discharge of sweat. If alcohol is taken in large doses to the extent of intoxication there is a tendency to reaction towards cold which exhausts the body temperature. Walther took two rabbits giving one 35 c. c. of brandy and the other none; on exposing the two to a temperature of 21 degrees below zero the first rabbit's temperature fell to 19 degrees while the second's fell to 35, in other words the former represented a fall of 19 degrees and the latter three. These results have been confirmed, so that alcohol given in large doses reduces the body heat and interferes with the organic power of regulating the body temperature. By the use of the calorimeter Reichert has proved that this variation is due, not to any difference in the heat production, but to excessive heat loss, resulting in the fall of body temperature. The testimony of Arctic explorers is that the use of alcohol does not aid the body to endure extreme cold. In regard to chloroform, ether, chloral, morphine, nicotine and quinine, the same effects are noticeable in connection with the body temperature, namely a reduction of the body temperature. If these are given in large doses the body loses its power of regulating the temperature, the temperature of the body following the same variations as we find in the cold blooded animals, varying very little from the external temperature. In connection with chloral it is found that the heat loss is from 30 to 40 per cent in excess of the heat production and that the heat production is lessened below the normal. In the case of the use of strychnine the production of heat is increased while the loss is lessened. Atropin, caffein, brucin, veratrin and cocaine produce also an increase of temperature while curari produces a marked lowering of the temperature. The effect of these poisons upon the temperature of the body being due partly to their action upon the tissues, rendering them partially incapable of the molecular changes that are necessary in the production of heat, makes them particularly disadvantageous to the system. Landois says that possibly in case of the anaesthetics, chloroform and ether, there is a semi-coagulation of the nerve substance producing incapacity to perform the metabolic functions associated with heat production.

8. Influence of Baths.—Hot or cold baths have much greater effect on the body than exposure to the same temperature of ordinary air, just as a moist bath has a greater effect because of the conductivity of water. Currie first discovered that on being plunged into a cold bath there was an immediate rise of temperature; but this was temporary being followed very rapidly by a fall of temperature which continued. He found that the depression of temperature was greater in the fresh than in the salt water. These observations were made in connection with the mouth temperature. Liebermeister observed the axillae temperature, finding that as a result of a cold bath there is a rise of temperature slightly, so that if the bath is moderately cold there is no lessening of the body temperature because more heat is produced in connection with the bathing than is lost. He found that the amount of heat produced in connection with the bath represented about four times the normal body heat. These

experiments have been confirmed, LeFevre finding that after remaining three hours in a bath at 15 degrees the temperature as indicated by the closed axillae has only fallen one degree, the fall in temperature taking place during the first half of the period; during the last half the temperature remained steady. In the case of a bath at 25 degrees there was a fall of one degree during three hours and in a bath at 7 degrees a loss of 1.7 degrees in one hour. The bath does not affect the temperature of all bodies alike, the effect depending upon the size of the body and the amount of adipose tissue. The smaller the body and the less the amount of fat the more rapid does the cooling process take place. In the case of a warm bath the general effect is to raise the temperature, followed by a temporary fall after the bath, then returning to the normal temperature. There are, however, great differences in individuals in this respect. It indicates the power of adaptation to external surroundings and the power of regulation possessed by the mechanism of the body in the case of the higher animals. A cold bath withdraws from the body a large amount of heat. This does not of necessity reduce the body temperature even slightly, because with the contraction of the superficial blood vessels the heat loss is lessened and the stimulation of the cold on the sensory cutaneous nerves stimulates heat production. In the case of a hot bath there is a rapid loss of body heat arising in connection with the vascular dilatation on the surface of the body, followed by a diminished production of heat. Thus the body possesses the power of compensation indicated by the rise in temperature in the body after a cold bath and the fall after a hot bath. This compensatory action of the body mechanism is so complete that where exposure to either cold or heat is extreme there is a rise or fall in temperature so as to equalize the conditions of the body and the external media. Hence the conclusion reached by the majority of physiologists is that baths do not affect or affect only slightly the normal body temperature. In the case of high fevers cold baths have been used effectively, because here the limit of compensation is passed and hence the effect of an extreme cold is more apparent.

Here we come to the subject of hydropathy or the treatment of diseases by water, whether externally or internally. The meaning of hydropathy is rather deceptive, because it is not a water cure, but the water furnishes the medium of heat and cold as applied to the body. Hydropathy originated in England in connection with the writings of Floyer and Currie. Currie's work on the effects of water, cold and hot, as a remedial agent put the subject on a scientific basis. The medicinal virtues of water had been advocated in the 18th century by a Sicilian monk but the Austrian Priessnitz was the first to apply the system. Baths had been in existence as medicinal agents, especially the warm bath, from very early times. The system was introduced into England in 1840 by Caridge, but it was not until 1852 that Smedley at Matlock founded the modern hydropathic institution. Since then it has been supported very extensively in England, Germany and France. On the continent of Europe Jurgensen and Liebermeister became distinguished advocates of the new institution. The foundation of this method of treatment is claimed to be in the human organism. The cells which constitute the body organism in their growth are dependent upon the nervous mechanism and especially upon the blood circulation as it is controlled by the nervous system. So close is this relation that every disturbance of cell function involves a disturbance of the nervous and vascular systems more or less complete.

The nervous mechanism and the vascular supply are governed very largely by the regulation of heat and cold, in other words with the maintenance of a normal animal temperature. It is for this reason that hydropathy claims heat and cold as deserving to be ranked as remedial agents, because of the influence which they exert upon body changes, particularly in rectifying morbid conditions of the system. To the hydropathist a diseased condition is the symptom of some cause of derangement in the body organism. When this cause has been discovered the hydropathist claims that the power of nature should be resorted to to restore it and only such remedial agencies made use of as are natural or physiological. Hence when in pneumonic lung conditions blood requires to be taken away from the œdematous part, this is done by diverting the blood to some other region of the body such as the cutaneous surfaces. The skin surface is selected as the storehouse of the blood because it is easy of access and less liable to produce permanent dangerous results than some of the other vital parts of the body. It uses the allopathic principles to this extent of establishing a counter irritation in the superficial regions of the body so as to abstract the blood from the affected part and drain it to an easily accessible region. The advantage hydropathically of the diversion of the blood to surface is to be found in the fact, that it is very easy to produce excretion in connection with the cutaneous surfaces of the body and so to drain off from the system an unnecessary supply of blood. In the case of fevers instead of using depressisg drugs the cold sheet pack and sponging are made use of to reduce the temperature of the body and to lessen the pulse rate as well as to allay the irritable condition of the system and induce normal sleep.

From the hydropathic standpoint cold is regarded as below 60 degrees F, warm over 90 degrees and moderate between these two temperatures. Hence there are varying degrees of heat and cold; and still further modifications may be introduced in connection with moist or dry heat and cold. The primary result of cold is to depress or cool and also to contract the blood vessels, resulting in throwing out the blood from the vessels. By the sudden application of cold there is set up a reaction in the opposite direction, resulting in stimulation increasing the blood supply and also the the temperature of the part. If the cold is continued in its application there is no reaction and depression continues. The primary result of heat is to produce an increasing blood flow. If the heat is applied only for a short time evaporation follows, with a reaction toward the cooling process, resultingin the removal of blood from the vessels. If the heat application is continued then the increased blood flow is also continued. In connection with moderate heat and cold there is a soothing effect, the result depending upon the the local heat or the general body temperature. In the case of local inflammatory conditions continued cold contracts, while continued heat dilates and soothes; sudden and briefly applied cold stimulates, then produces heat and therefore increases the inflammatory condition; sudden and briefly applied heat cools the part because it produces heat evaporation from the part. Hence hydropathy in acute inflammations applies either the continued cold or the momentary heat; while in chronic cases of inflammation, especially if these become congested, momentary cold applications are used. If accompanying the local inflammatory condition there is a general body fever, the application of continued cold tends to produce evaporation of the general heated condition. In connection with the internal portions of the body heat and cold

have their effects through the nervous system, the principle of sympathy being applied in connection with cutaneous heat and cold applications so as to reach the kidneys, the stomach, etc. Various appliances are made use of in the application of heat and cold to the system hydropathically. Among these are, (1) Formentations both hot and cold; (2) Compressed wet bandages used in local and inflammatory conditions so as to assist heat evaporation and also used in cases of congestion with an oilskin covering so as to produce heating: (3) Baths both hot and cold, whether general in the whole body or local, such as the foot or head bath, in cases of vascular stag nation or nervous debility; (4) The hot air and steam baths, principally the Turkish bath which has a tonic and alterative value in increasing the tissue metabolism and the waste elimination, as well as reducing internal congested conditions by determining the blood to the superficial regions of the body. In rheumatic and gouty cases these are used to facilitate the removal of dangerous acids that are liable to accumulate in the tissues of the body. (5) The sheet pack. This consists of a full wet sheet encasing the entire body. The patient is then placed in bed and covered up with sufficient clothing to retain the heat around the surface of the body and after one or two hours the patient is given a general body bath. This is done to stimulate the cutaneous excretion.

In most of the morbid conditions of the body system there is either direct or indirect disordered condition both of the digestive and metabolic functions. As a result the blood is more or less affected, being involved in a slight or complicated oedema. This inflammatory condition affects the excretory system also, the impure blood continuing the morbid condition and increasing it as it extends to the different parts of the system. Hydropathy claims that there is here a chain of disordered conditions extending throughout the entire body economy, so that in order to prevent this morbid condition from becoming master of the body organism the chain must be broken. It is in order to break this chain that heat or cold is applied to the blood and as the blood can best be reached by attracting it to the surface of the body, it is claimed that the application of hot or cold water can best secure this result without injuring the system by the introduction of any foreign substance. The cutaneous surface becomes the seat temporarily of the greatest vitality, the result being a true metastasis when the morbid condition is transferred from the seat of disease to the superficial surface in connection with the blood circulation. The result is that the internal disturbance is lessened by the removal of the pathological elements in connection with the blood, brought to a region where easy elimination is possible, this elimination being rendered possible and greatly facilitated by the means adopted to open the cutaneous excretory organs. Hydropathy, as we have traced it, at least emphasizes the primary action of baths, namely, the influence of heat and cold upon the superficial body surface as it is applied through the medium of water. It also emphasizes the fact that the body temperature has much to do with the nutrition of the body and that under the influence of changes of temperature the body functions may be stimulated to an increased activity, rendering them capable of throwing off abnormal elements. The primary purpose of baths is cleanliness, to cleanse the body surface so as to remove foreign substances, to keep the skin in a healthy porous condition and to promote normal cutaneous excretion. Some believe that one action of of water in connection with the bath is its absorption through the skin. There is however only a very slight absorption if any in connection with

bathing; and this would seem to indicate that the so called medicated baths are of little value, aside from their stimulating action upon the skin. The action of water upon the skin capillaries depends largely upon the water temperature. It must be remembered that the body can bear changes of temperature in dry air much better than in a water medium. A temperature of 80 or 90 degrees in water is very much more irritating than the same temperature in air because the body is heated without any chance of evaporation and the perspiration is retarded. The cold bath is of value chiefly in connection with the process of cooling, although the degree of coldness has much to do with its beneficial or dangerous effects. When the cold bath is above 49 degrees the skin temperature is lessened, the blood temperature which at first rises then falls, although not till after leaving the bath. The skin becomes more or less numb and pale, the effect in the form of a slight shock being communicated to the heart, lungs and nervous system, the shock being evident in some cases in tremulation, with thoracic depression and a weakened pulse. After the removal from the bath the reaction sets in, the temperature of the body increases, the pulse and blood circulation becoming more rapid. If the water is colder and especially if the water is in motion there is liable to be a dangerous effect upon the system. The effect of water applications depends upon the ability to withdraw body heat and to increase body heat, in other words depressing or stimulating the system. The depressing effect may arise in connection with a heat loss associated with retarded circulation. The stimlating effect arises in connection with increased cardiac and pulmonary activity, together with muscular and nervous stimulation; for example in the case of moderately cold baths when the water is kept in motion, so that the body is continuously subjected to the sensations that produce such stimulation. Depression is produced much quicker in very cold than in warm water and stimulation quicker in colder that in warm water, the shortness or length of the bath period varying the intensity of the sensation, either less or more. In this way by alternation of depression and stimulation there may result the stimulation of the nervous system and circulation of the blood, the absorption and secretory processes and also the excretory sweat processes, resulting in active metabolic changes takine place in connection with the body tissues.

Cold baths tend to retard perspiration, hot baths to assist and increase it. Cold baths, and also hot baths to a certain extent, assist the urine secretion. It is claimed by some that cold baths assist the, secretions chiefly the gastric juice, while hot baths decrease them. In both cases there is an increase in oxidation in connection with the tissues; in the case of a warm bath however there is less drainage upon the system in heat production because the bath supplies the increased heat. In the case of exhaustion a hot bath is refreshing while a cold bath is depressing, because the heat added to the systen increases the oxidation process and throws off some of the accumulations. Cold stimulates the functional activity, whereas heat sets them free from incumbrance. Very warm baths have much the same effect as cold baths, stimulating the heart activity and the nervous action, but the effect takes place with less shock to the system This leads to the conclusion that warm baths are more beneficial than cold baths, because their action has less shock upon the system and the system can stand better the milder and more gradual effect of the warm bath. Hence the warm baths are more suitable in the case of the young and old and those of weak constitution, whereas the cold bath is better for the strong and

vigorous. Hot baths too frequently or injudiciously taken are wasting on the system. This is equally true of hot baths continued too long, producing weakness, brain congestion and even apoplexy, the effect being a paralysis of the heart through the nervous system. In the case of cold baths too long continued there is danger of internal congestion. Hence system in bathing and judiciousness in the selection of the nature of the bath form the essential precautions to be taken in connection with the use of this natural means of promoting health and removing disordered conditions.

9. Abnormal Conditions.—In the case of hemorrhage there is a fall of temperature at first but it is soon followed by a rise and is usually associated with a rigor condition. After some days the normal is resumed and sometimes there is a fall below the normal. if there is a loss of blood suddenly and to a a large extent there is a marked temperature fall from one to two degrees, cases being on record in which a fall to 29 or 30 degrees has taken place. This arises from the lessening of oxidation processes and to the fact that the blood circulation becomes feeble. The small effects may be found associated with diminished metabolic activity or interference with the action of the heart as in the case of the stimulation of the peripheral end of the pneumogastric which has the effect of slowing the heart. In connection with the transfusion of blood there is found a rise in temperature shortly after transfusion, representing a fever condition which continues for some time and then passes away, the normal being resumed. In some abnormal conditions such as cholera, diabetes and the final stages of insanity there is a fall in temperature amounting sometimes to 9 or 10 degrees. In fever conditions we have the temperature varying from 37.5 to 41.5 degrees C and in certain stages where the results are fatal as high as 45 degrees. If the temperature is mantained for any length of time above 42 or 107. 6 F. fatal results are certain to follow. We have recorded cases of extraordinary temperatures in which life was preserved, one case of hysteria being reported at 50 degrees C or 122 F.

SECTION V. The Regulation of Body Temperature.

Temperature depends on the vital activity and it is necessary to the vital existence. Each animal has its own definite body temperature. In life there is a constant production and loss of heat. To make this consistent with the statement that man ranks among the homoiothermal animals we must show how the regulation takes place so as to preserve uniform and constant the body temperature. When there are changes in the temperature of the environment the body mantains a steady temperature. If the heat production and loss balance each other the temperature remains uniform; whereas if the heat production or loss is either in excess or falls below the standard there is a disturbance of the temperature balance and therefore a change of temperature. It is not necessary that because the heat production is altered the body temperature changes, because the heat loss may also be altered so as to balance with the gain. A change in temperature may be produced by alteration therefore in the production or loss. We must remember that the temperature does not vary with the production of heat. In cases of fever an increase of body temperature represents an increased production and a decrease in body temperature a decreased production, fever may however be partially due to the heat loss. The variations in temperature therefore simply in-

dicate a disturbance of the heat balance and the question we are here to discuss is not that of the production or loss of heat but how the balance may be restored. As the temperature varies in different animals under varying conditions there must be differences in the power of regulating temperature. In the human subject we find the most perfect development of this regulative power so that in the frigid regions equally with the temperate and torrid zones his temperature remains almost invariable. The same thing is true of very great increase in temperature for a short period, because man may stand a temperature cousiderably above 100 C for a short time without almost any change of temperature in his own body. In the case of other mammals this can not be done, indicating the more imperfect regulative power in these animals. In imperfectly developed or weak mammals the regulative power is also imperfect as they lose temperature on exposure to the cold and thus approximate to the cold blooded animals. Among the cold blooded animals there is also a considerable variation in the power of regulating the temperature, most of the cold blooded animals having hardly any regulative capacity. Even where animals have the power of regulating the temperature this power is exercised only within definite limits. If the limit is over-reached there is a fall in the animal temperature, unconsciousness follows and the animal is said to freeze to death. The same is true in regard to extreme heat, the point being reached beyond which regulation is impossble. This implies that heat production can be lessened but not suspended. it can be increased but this can not be carried out indefinitely for when the atmosphere becomes greater than body temperature especially if moist then heat loss from the body is hindered, producing a rise in temperature internally that is opposed to living conditions. There can be no perfect balance of heat and loss in the case of extremes of heat and cold from a regulative standpoint.

The regulation of temperature then has two phases, the regulation in connection with heat loss and heat production. In connection with this an important law is that of the conservation of energy, because it represents the physical balance between heat production and loss. When work is done against forces or stress from a physical standpoint the work is not lost but the energy is transformed and conserved. Clerk Maxwell defines the conservation of energy thus, "The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of these bodies, though it may be transformed into any of the forms of which energy is susceptible." Hence if a body is unaffected by external bodies there will be constancy in the amount of energy it possesses, whereas if there be action in connection with some external bodies a certain amount of the energy will be transferred to that work or to the other bodies involved. This implies that there is a conservation of force within the body, the energy being changed in form so as to favor its application in some other direction. This law is at the basis of the regulation of the body temperature. This transformation which takes place within the body and which does not involve any loss of energy so far as the mutual action of the different parts of the body is concerned may be accomplished in two ways, by regulating the transformation of potential energy into heat or by altering the amount of heat loss from the body in relation to the production of heat. This law is at the basis of the distribution of heat throughout the body and the tendency to equalize the body temperature normally when through

some external cause some of the body heat is taken away.

In connection with this we find that there is a regular heat mechanism which preserves the constancy of the temperature. In this heat mechanism we find three cooperating agencies, (1) the thermogenic in connection with heat production, (2) The thermolythic in connection with heat loss, and (3) The thermotaxic in connection with the balancing of the gain and loss of heat so as to produce heat equilibrium. The action of these mechanisms maintains the balance of temperature representing change either in production or loss or in both. (1) Thermo-genesis. In connection with heat production which we will discuss later we find that the tissues of the body are actively engaged. Nearly all the body tissues are at work in producing heat. The processes of oxidation are essential to the body activity and also to heat production so that wherever oxidation takes place there we have the production of heat in connection with cell activity. While this is true of all the body tissues there are certain parts of the body that are especially active in heat production. In the case of the skeletal muscles this is said to be their special physiological function, the heat production taking place in them under all circumstances. During muscle contraction there is a certain amount of work done and associated with the work done is heat. During contraction the muscles are active the increase of heat being accompanied by a larger O consumption producing a more venous blood. When the voluntary muscles become active there is a considerable increase of heat. During the period when muscle is resting heat production continues in connection with muscle growth and also in the active production of heat. Even when muscle is inactive so that there is a suspension of the chemical changes taking place in connection with muscle activity there continues to be the evolution of heat. Here the law that regulates the heat supply is that of economic demand, the active tissue changes producing heat, all the tissues being correlated so as to produce sufficient for the body system under the control and direction of the nervous system. In muscle contraction it is estimated that about 20 per-cent of the energy evolved represents mechanical activity, the remaining 80 per-cent representing heat. In connection with the active cardiac contractions there is also a heat production, the blood circulation contributing a large proportion to heat volume on account of the resistance to the flow of blood found in connection with the vessel walls, particularly the arterial walls. The heart activity and the circulatory resistance converted to heat represent about one-twentieth of the entire heat production in the body. Other organs of the body, especially the glands, chief among which we find the liver, represent in their great secretory and metabolic functions heat generation. When the body glands are active in secretion heat is produced as is evident in the temperature of the blood leaving as compared with that entering the glands. For example, the sub-maxillary gland according to Bernard when very active rises in temperature even though the O consumption is less. The digestive organs when active also produce heat and associated with this is the use of an increased amount of food in colder weather as compared with warmer weather.

This heat generation takes place throughout the entire body wherever activity of organic function is found. It is regulated, however, by the nervous system. The nervous system directly stimulates the molecular changes which produce heat, but in addition the nervous system is regulative. If an animal is given curari there is a fall of temperature

and metabolism decreases, the latter producing the former effect. If exposed to higher and lower temperatures the body temperature rises and falls respectively and the animal becomes really like a cold blooded animal. It is true that even if the nerve connection is cut off from a muscle heat generation continues, although it is considerably lessened. But in the production of heat when thus severed from the nerve connection it has ceased to be correlated to the rest of the body and, hence, there is no regulation of the heat supply. This is evident in certain cases where the spinal cord is injured, the amount of heat being altered. injury either increasing or decreasing the amount of heat produced. Attempts have been made to localize heat fibers but so far without success. It is claimed that in connection with muscle changes there are two processes of katabolism, the one bearing on muscle contraction and the other on heat production. If this is so these dual processes must be regulated by two different sets of fibers. In the case of muscle contraction the katabolism seems to depend distinctively on motor nerve fibers, while in the processes of heat production the nerve fibers are not of necessity motor fibers but have been called thermogenic fibers, directly bearing from the heat centers impulses that are of value only in connection with heat generation. In the former case through muscle contraction muscle tone is not necessarily preserved whereas, in the latter case in connection with the heat impulses, the muscle tone is preserved. The nervous control of the heat production is proved in the case of a section of the different nerves. When the temperature falls the metabolic changes are lessened and less CO_2 is found in the blood than usual. If the sciatic of a rabbit is divided on one side and it is then placed in a warm room the limb in which the sciatic is intact will sweat profusely, whereas the other in which it is cut will not, indicating heat loss through nervous control. If a rabbit's sympathetic is divided the vessels of the ear are dilated and there is a rise in temperature, whereas stimulation produces a fall, indicating that the nervous system regulates heat distribution. In what way the sensory impulses originate that give rise to these reflex thermogenic actions is not known but it is certain that the impulses originate in the superficial body surface. The application of cold to the skin seems to excite the sensory cold or temperature fibers which stimulate reflexly through the centers the heat fibers of the muscles regulating the production of heat.

While we do ~~not~~ know definitely the existence of heat fibers we do know that there are heat centers. When the skin surface is excited by cold or heat there is a definite heat production. This does not depend on vaso-motor action but it is due to thermogenic stimulation. When certain parts of the brain are stimulated artifically or injured as by puncture there follows heat production or diminution, depending on the part of the brain injured or stimulated. Injuries of the spinal cord have a similar effect. When the cerebro-spinal axis is operated on in certain of its parts there is found an accumulation of CO_2 or a decrease in the amount of CO_2, indicating an interference with the process of heat formation. In connection with the cerebro-spinal axis definite regions have been localized which are found to be concerned in heat production, so that when these parts are either irritated or destroyed there is an interference with heat production. These experiments have led to the localization of a cerebro-spinal area, some regions corresponding with heat accelerator centers, other regions with heat inhibition centers while there is another region localized as the automatic heat region. The automatic centers are con-

cerned inpreserving and governing the normal heat production whereas the acceleration or diminution of heat production is regulated by the specific accelerator part or inhibitor centers. Several experimenters have identified certain regions in the brain cortex, in the basal portion of the brain anterior to and beneath the corpus striatum, within the corpus straitum, in the optic thalamus, in the prominence of the gray matter between the optic tracts and the corpora albicantia, in the wall between thelateral brain ventricles, in the corpora quadrigemina, in the pons Varolii, in medulla and in the spinal cord. Great difficulty has been experienced in identifying these centers because in order to localize definite points injury is necessary and an injury to the cerebro-spinal axis inxolves difficulties that are hard to account for. The chief methods have been stimulation, electricall or mechanically by a probe or cautery and destruction by incisions into and across the cerebro-spinal axis. Here a distinction is drawn between thermogenic and thermolytic centers according as stimulation or destruction affects the production or loss of heat. The general heat centers are always in active operation while the acceleratory andinhibitory centers are only activeintermittently, accordingto the necessities of the system. Reichert, whose investigations on this subject are the most recent and thorough, localizes the general heat centers in the spinal cord, the heat centers in the brain being either acceleratory or inhibitory, the former centers being found in the optic thalamus, the pons, the medulla and the tuber cinereum. On stimulating these regions there is a rise of temperature and the destruction of any one region may or may not be accompanied by decreased heat production, this decrease being produced by the injury to the part of the brain. In the pons and medulla there isa common center but the most powerful thermo-acceleratory influence is associated with the base of the cerebrum. Inhibitory centers are identified in a dog with the cruciate groove and the junction of the post and supra Sylvian fissures, stimulation of these being accompanied by decreased heat production and their destruction by a temporary increased production. If however the spinal cord is divided at the juncture with the medulla all of these centers cease to act. This has led to the conclusion that the primary heat centers are in the spinal cord in connection with the anterior cornua. These centers are closely connected with the centers in the brain by nerve fibers so that as the impulses pass from the acceleratory or inhibitory centers the general centers are either stimulated to activity or inhibited. The spinal centers are not directly influenced by cutaneous impulses arising from external stimulation or blood changes whereas the brain centers are directly influenced by these impulses, so that when these impulses reach the brain centers it is through these centers that the spinal centers are affected. In this way when the blood temperature rises or when the cutaneous nerves are stimulated by an increased external temperature the inhibitory centers are influenced so as to send down inhibitory impulses to the spinal centers; when the blood temperature falls and the external temperature falls impulses are communicated to the acceleratory centers from which acceleratory impulses are sent down to the spinal centers. In the former case the spinal centers are less active and in the latter more active.

(2) Thermolysis. The body loss of heat represents not a direct reflex action in connection with the heat mech-anism but rather an incidental circumstance attending other conditions.This means that the body is rather inactive in the loss of heat, just as under the ordinary physical

laws any physical and lifeless body would lose heat. In the living body however there is this difference that theloss of heat is regulated at least in its rapidity by the vital activity.

The thermolytic mechanism is complex. The physical properties of conduction and radiation in connection with the skin surface, water evaporation from the lungs and the surface of the body, the heat imparted to the colder organs and especially to the alimentary organs in connection with the heating of cold food account to a large extent for the heat loss. Hence whatever influences the circulation of the blood towards the periphery, the excretion of the sweat and the inspiration of air as well as the form of food, influences the heat loss. By increasing the body temperature the heart becomes more active, the blood vessels of the peripheral surface become distended, respiration is increased in activity and sweat excretion becomes more profuse. This determines the blood to the surfaces of the body in larger than normal quantities; and bringing it into contact with a cooler medium than the interior of the body provides for heat radiation. Profuse prespiration increases the water evaporation and with it the heat evaporation. Increased respiration increases the volume of air taken in, heat being expended in warming it and also a greater expiration which means the expiration of vapor and a loss of heat. Hence the cardiac, vaso-motor, respiratory and sweat mechanisms are involved in thermolysis, the activity or inactivity of these depending upon blood temperature and skin temperature, especially in connection with external temperature changes. When these mechanisms are active there is a large heat loss.

(3.) Thermolaxis. This represents the heat regulation from the standpoint of gain and loss. This is accomplished in connection with the correlation of thermogenesis and thermolysis. Ifthe heat production is greater than the heat loss, then the loss of heat is increased so as to preserve the average body temperature. If heat loss is greater than heat production then the thermogenic processes are increased so as to compensate for the loss. These correlative actions are dependent upon the blood temperature and the influence of the external temperature through the cutaneous sensations. If the temperature of the blood increases this produces thermolytic action. When the body is subject to cold external atmosphere there is an increased heat loss but at the same time through the skin impulses are sent to the thermogenic centers which arouse heat production. Thus in normal conditions is kept up a continual balance between heat production and heat loss so that the correlative action is complete. This balancing is carried on largely in a reflex manner, chiefly through the cutaneous impulses. The application of cold to the surface of the skin for a short time contracts the superficial blood capillaries, producing a diminution in blood heat and volume, thus preventing heat loss by radiation and conduction. Accompanying this there is a diminished sweat excretion, lessening the heat evaporation. At the same time there is an increased heat loss through radiation on account of the difference in temperature between the body and the external medium so that there is an increased heat loss. When this takes place heat production is stimulated reflexly through the cutaneous nerves, heat production being increased and a temporary rise in body temperature of about .3 degrees C following to be followed by a reaction in the fall of body temperature .3 degrees, followed by another reaction above the normal heat and so on till the normal is restored. Moderate heat applied to the surface of the body

produces distension of the superficial vessels, increases the circulation of the blood and therefore the blood volume, the respiratory activity and the sweat secretion, at the same time decreasing heat production. By increased blood circulation at the superficial surface there is a heat loss by radiation; increased respiration introduces a fresh supply of air to be warmed and a greater expiration evaporating water. Sweat increase also increases the water evaporation and heat loss. When the external temperature is above the body temperature there is no loss from the body by radiation and conduction so that in the main there is heat gain. Here arise reactions in connection with the distended superficial vessels, increased respiratory and sweat activity, lessened muscle tonicity and lessened heat production, due to the diminished muscle activity, so that the balance of heat gain and loss is maintained. There is a limit to this heat regulation for when the external temperature becomes either cold or hot to an extreme, then in the case of extreme cold heat loss exceeds heat production to such an extent as to lower the temperature below life conditions; and in the case of extreme heat heat loss is prevented so that heat accumulates in the system producing a rise in temperature fatal to life. Thermotaxis as Reichert points out may be abnormal where on account of abnormal conditions of body temperature a new adjustment of the regulative apparatus is required. This readjustment can take place either supra or sub-normal the former being found in the case of fever and the latter in the case of fall of body temperature. The delicacy and accuracy of this regulatory power is evident from the fact that in fevered conditions the centers are adjusted to the body condition and maintained at this abnormal standard.

At any period the heat of the body is approximately uniform through the body, about 37.4 degrees C. This uniformity is secured by the circulation of the blood which carries heat to the portions where heat is lost and takes off heat where it is too great. Of course all the parts of the body are not uniform because the different parts have different temperatures.

From the standpoint of thermotaxis the nervous system represents the most important condition regulating heat production and loss so as to produce normal thermal equilibrium. In connection with the heat loss the vaso-motor system is very important because it regulates the bood supply in the superficial and internal parts of the body. The respiratory center is also actively engaged in regulating the frequency and the depth of respiration. The nervous system also regulates the muscle metabolic changes. This regulation takes place reflexly by the sensory cutaneous nerves which are the chief paths of afferent impulses.

(a) VASO-MOTOR INFLUENCE.—The heart is the source of the blood as distributed throughout the body and the heart represents aside from the liver one of the warmest of the body organs. From this warm center the blood is carried to the superficial parts of the body where the temperature is much lower. Rosenthal distinguishes three separate body regions, an internal region that is warm and an external region that is cold and between these two a temperate region that is moderately warm. The warm region represents the internal organs and tissues of the body, the temperate region the intermediate parts, whereas the cold region represents the skin and sub-cutaneous tissues. Normally the temperature increases from the external to the internal, because the chief sources of heat are found in the warm and temperate regions of the body, whereas

the greatest heat lossis in thesuperficial region. By the circulation of the blood the warmer blood is constantly being brought to the cooler regions and vice versa. The difference in temperature between the internal and external regions will therefore depend very largely on the amount of blood circulated and the rapidity with which the circulation takes place. This is controlled as we have seen before by the vaso-motor system through its constrictor and dilator impulses. The vaso-motor center is in the medulla and possibly auxiliaries are found in the spinal cord. By the constriction of the cutaneous vessels the amount of blood circulating in the superficial parts of the body in diminished, resulting in diminished temperature and therefore less heat loss. This in accomplished in connection with external cold so that the body temperature is thereby preserved and may be even increased as is evident from the first effects following a cold bath. If on the other hand warmth is applied to the external surfaces of the body the cutaneous vessels are dilated producing an increase in the blood volume and an increase in the temperature of the surface of the body and so a loss of heat. Thus the use of a hot bath cools the interior of the body and this may be very rapid as we find in the case of ague sweating when it becomes profuse being marked by a fall in body temperature. These cutaneous blood changes can be accomplished not only by the use of cold and heat applied to the surface of the body but also by the feeling and emotions such as pain, fright, the emotions having different effects in different individuals. Brown-Sequard claims that the influences which affect one side of the body are conveyed to the opposite side, claiming that to place the hand in very hot water raises the temperature of both hands.

In connection with vaso-motor action certain difficulties arise in attempting to explain the action upon the changes in temperature. Associated with the superficial vascular changes is an increase or decrease of sweat excretion and also a change in connection with tissue metabolism. Bernard found that by dividing the cervical sympathetic there was a dilatation of the blood vessels and an increase in temperature in the case of the ear on the same side as the division. This dilatation produced an increased blood supply with a greater rapidity in the flow and therefore a rise in temperature. Bernard claimed that the regulation of the heat as well as the blood changes were direct in connection with the nervous system and that the former did not result simply from the latter indirectly. This was confirmed as he thought by the fact that when the veins of the ear are ligatured before dividing the sympathetic increased temperature still resulted. According to this theory of Bernard vaso-motor action did not increase the temperature but there is a special thermogenic nerve connection so that the vaso-constriction and tissue thermation represent distinct nervous actions. This theory was opposed vigorously by other experimenters who claimed that while the tissue metabolism does influence to a slight extent the heat production, in the case of the ear the cartilaginous tissue is not the center of any active metabolic changes. They claim that the increase in temperature is due simply to the supply of blood greater in amount and more rapid in circulation. When the cervical sympathetic is divided on one side only the the temperature in the one ear represents an increase of from 10 to 16 degrees. Schiff claims that the difference between the two ears is in direct proportion to the difference in amount of blood found in each ear. If before dividing the sympathetic the subclavians and cartoid on the same side are ligatured there

is a fall in temperature because of the lack of circulation. In proof of the fact that rise in temperature depends upon the blood it has been shown that with the sympathetic intact, by ligaturing the subclavians the blood pressure may be so increased in the cartoid artery as to raise the temperature of the ear, so that the regulation of temperature takes place it is claimed in connection with the blood supply under the vaso-motor control. Besides the superficial vaso-motor connection there are also vaso-motor connections to the lungs and other respiratory organs which must have an important function to discharge in heat regulation. This of course depends to some extent on the animal. For example in the case of a dog which has a thick fur covering over its body the respiratory activity is manifested chiefly in connection with the tongue. This respiratory activity in the dog is very great as it is estimated that in extreme heated conditions the dog respiration represents 170 to 200 per minute as compared with a normal of of 25 to 30, Richet estimates that every hour one gram of water is excreted for every kilogram of body weight when the external temperature of the surroundings is normal; whereas in cases of large increase of the external temperature this may be increased ten-fold, the respiratory activity increased to 200 per minute. Experiments have been made in connection with the muzzling of dogs to prove that where the respiration is prevented or interfered with in any way the temperature of the body rises.

(b) THE INFLUENCE OF THE SPINAL CORD. In connection with the spinal cord, important conclusions have been reached particularly in injured and divided conditions. Many contradictory results have been reported but these can be explained largely on the basis of different conditions under which the different experiments have been made. This brings out some important considerations, for it is found that different results are found in connection with injuries at different parts in the spinal cord. If the division takes place high up in the cord the paralytic condition will be more extended resulting in a very much lessened heat production and a much increased heat loss. This arises from the loss of control in connection with the nervous system producing cutaneous dilatation. Similarly a division high up in the cord will interfere with the respiratory activity, whereas if the division is low down respiration will be only slightly if at all affected. Where the division of the cord takes place very low down there is greater capacity of adaptation, so that while the loss and gain of heat are affected the control exerted through the remaining parts can adapt the heat production and loss more readily to the body requirements. The superficial mass of the animal has also something to do with the effects, because where the animal is larger the superficial surface is smaller relative to the body size and for this reason the heat loss will be less in connection with vaso-motor paralysis. Variations will also be found in the case of different animals depending on the mechanism of heat regulation. In the case of the dog the respiratory action largely regulates the body heat whereas in the case of man respiratory action is small compared with the vaso-motor action. Even among human subjects great variations exist as is found by comparing persons who sweat freely with those who sweat little. All of these conditions are modified considerably by the surroundings of the animal. For example the external temperature considerably influences the heat production and loss. Dogs extend themselves when warm whereas when cold they coil their limbs and body together. In cases of vaso-motor paralysis such conditions are impossi-

ble so that posture can play only a very small part in cases of vaso-motor paralysis.

Brodie was the first to observe that when the cord was divided high up in the cervical region the blood circulation was not suspended, if the respiration was kept up but that even in preserving the circulation the temperature falls rapidly. This is due to the heat loss in connection with the blood circulation, as by stopping the circulation the fall in temperature does not take place so quickly. Similarly by the use of curari in the case of animal poisoning the nervous activity is suspended and this is accompanied by a fall of temperature, although the CO_2 discharged is not affected. This he claimed to be a proof of the fact that heat production does not depend on the chemical changes associated with the blood and the other tissues but on nervous influences. Phillip found that in the case of artificial respiration there is a loss of heat even in uninjured animals while in the case of the extirpation of the brain slow artificial respiratory action retards the fall of temperature, the temperature in some cases being slightly raised. The fall in temperature is much less than in the case of a dead animal and during the cooling process more meat is lost than in the case of a dead animal. In confirmation of these results it has been found that artificial lung ventilation in a normal animal lowers the temperature and that any interference with respiratory activity also lowers the temperature and that the continuation of lung ventilation artificially may so lower the temperature as to produce death. Division of the spinal cord between the third and fourth vertebrae produced a fall of 6.8 degrees in a rabbit. This was due to the increase of heat loss due to paralysis of the cutaneous blood vessels and to lessened production of heat. The higher up the division the greater the loss of heat. When the peripheral end of the cord is stimulated the dilatation of the blood vessels is diminished and heat loss is lessened. Division of the spinal cord at the upper part of the dorsal region produced in the case of a rabbit a fall in temperature of 16 degrees in five hours and in guinea pigs a fall of 22.9 degrees in 24 hours when death took place. In the case of dogs the division of the dorsal and lumbar regions of the cord produces a fall in temperature, a division of the cervical region producing a slight rise from one half to one degree, Fischer concludes from this that there is a thermal center of inhibition in the cervical region of the cord. In the case of crushing the spinal cord in dogs it has been found that crushing at the 6th cervical vertebra produces a fall in temperature, if however the external temperature is high the body temperature rises two or three degrees. From a number of experiments Quincke concluded that nerve fibers extending from the brain to the spinal cord inhibit the heat production so that when division takes place there is an increase both of heat production and loss. Rosenthal never found any rise of temperature by crushing the spinal cord unless the external temperature was increased. He claims that a fever produced a rise in temperature in the other cases. Others explain this as due to the fact that the quick breathing was destroyed and therefore the temperature rose on account of respiratory suspension or inhibition. It has been found that by simply exposing the spinal cord without any injury the temperature of the body is raised. In connection with respiration Pfluger after dividing the spinal cord in the lower cervical region found that by increasing the external temperature the body temperature increases; by diminishing the external temperature the body temperature falls. This applies equally to the action upon the metabolism

of the tissues. The general conclusion drawn by Schaefer is that in case of the division of the spinal cord in the lower cervical region the body temperature falls and that this fall is due to lessened metabolism in connection with the muscle activity on account of paralysis and also on account of the heat loss arising in connection with the paralysis of the vaso-motors.

In other cases where the rise or fall in temperature is attributed to direct thermal nervous influence the effect is due rather to the changes in external temperature and to interrupted or retarded respiration, especially in the case of dogs. The respiration in the case of dogs is a much more important factor in the heat production and dissipation than in the case of man. A large number of cases of crushed spines have been reported and are cited by Schaefer, the crushing taking place between the fourth and seventh cervical vertebrae, some indicating a fall in temperature and others a rise the variation in temperature being about 33 to 43.9 degrees. In two cases the temperature is reported at 27.6 at or shortly before death. No general principles can be set forth to explain these cases because there have not been sufficiently careful observations to discover whether the temperature changes are due to deep or superficial changes in the body, or to respiratory changes so that nothing definite can be determined as to how much of the effect is due to the injury to the spinal cord. Pembrey in the British Medical Journal during 1897 reported his own careful observations in two cases of injuries to the spinal cord in human subjects. He found that in both cases there was a lowered temperature as long as the condition was not complicated by other disturbing conditions. This lowering of temperature was due to diminished heat production and to great loss of heat arising from the vaso-motor paralytic condition. The spinal cord may be divided into two sections so far as it has a bearing upon heat production and heat loss, the cervical and the lower regions; (1) the division of the cord in the dorsal and lumbar regions does not affect temperature regulation to so great an extent as (2) the division of the cord in the cervical region; and (3) the division of the spinal cord high up in the cervical region affects more seriously the temperature regulation than lower down in the cervical region. From this we can conclude that the cervical region has a more important function to discharge in connection with heat production and loss than the lower regions. When the cord is divided high up in the cervical region the power of heat regulation is altogether destroyed. In the case of the paralyzed condition involved in the section of the cord the body temperature rises and falls with variations in the external temperature. When the external temperature is high the parts that are paralyzed cease to sweat; the respiration is retarded being confined to the diaphragmatic respiration so that lung ventilation is hindered, less heat passing off during expiration and less heat being required to cool the inspired air. Similarly the metabolism of the tissues depends upon the external heat so that of the external temperature is higher, the metabolism is greater producing a greater amount of heat.

(c) The Influence of the Brain.—It is impossible definitely to decide how the temperature regulation is affected by the brain. Tscheschichin found that on dividing the medulla and the pons in the case of rabbits the temperature rose, in one case the rise being 3.2 degrees with a corresponding pulse and respiratory increase. At the same time he found that by dividing the spinal cord between the third and fourth cer-

vical vertebræ there was a fall in temperature, in one case amounting to 6.5 degrees. He concluded from his experiments that there is an accelerator center in the brain and also an inhibitory center in the brain regulating heat variations. Various other experimenters took up the same and similar cases and found contradictory results. Heidenhain found that by puncturing between the medulla and the pons the rise in temperature was more marked all over the body both internal and external, indicating that there must be an increase in the heat production. Bruck found that by electrically exciting the junction of the medulla and pons the same result followed and that this was due to the stimulation of injury. Later it was found that by injuring any portion of the pons, the crura, the cerebellum or cerebrum there was a rise in temperature if too rapid evaporation of heat was prevented by covering the body. Landois found that by destroying part of the brain cortex close to the cruciate groove there was a rise of temperature which was more marked on the side of the body opposite to the injury. This it was claimed arose in connection with disturbed vaso-motor action. Injuries to the frontal lobe and to the corpora striata produce a rise in temperature. Sachs reports that in using a very delicate probe no change in temperature was found in connection with the puncture of the cerebral hemispheres but a puncture through the median portion of the corpus striatum did produce a rise that continued for several days, similar to that producd by electric excitation of the corpora striata. In these two cases the superficial temperature as well as the internal temperature increased and respiration was increased, together with an increase in nitrogenous excretion. From this it was concluded that the increased temperature depends upon increase in metabolism arising from the excitationof the corpora striata. These experiments have been applied to the optic thalamus so that the corpora striata and optic thalami evidently have the power of regulating in some way the body temperature and this is not accomplished through the vasomotor system but directly. It is this evidence that we have referred to already in connection with the thermal centers. Aside from these thermal centers the mechanism of heat regulation is associated with vasomotor action and with the influences of the respiratory centers. It seems probable that the thermal centers have to do with the control of temperature in connection with the metabolism of the tissues, producing increase of metabolism when there is a tendency on the part of the temperature to fall and vice versa. Hence when the centers are away there is no control of the metabolism of the tissues and for this reason the tissue metabolism is governed by external circumstances.

Heat loss is regulated either voluntarily or involuntarily. As we have seen it depends largely on the conitdion of the cutaneous blood-vessels and these are subject to nervous control. When the skin is cold it is pale and the blood vessels are constricted. When the external atmosphere is hot the skin becomes flushed, the vessels are distended and there is an increase of temperature. Here the organism endeavors to to sustain an equilibrium of temperature so as to regulate the loss of heat in connection with radiation and conduction. It is possible to regulate the body heat even in very extreme cases of heat and this depends largely on the dryness of the air as distinguished from its moistured. The reason of this is that when the air is dry there is a free sweat excretion and evaporation and this tends to cool the surface of the body so that the heat is not felt so intensely. When the air is saturated with moisture there is

not much sweat excretion and little pulmonary excretion of heat is possible, so that as the heat is accumulated in the body the temperature becomes excessive resulting in death. In the case of extreme cold the thick fur of the arctic animals assists in the prevention of heat loss. It is found that increase or decrease of external temperature has a modifying effect on the coat of fur, hair or wool becoming thicker when the cold becomes intense and lighter where the heat is increased.

In the case of man however these involuntary factors are not of so much importance as the voluntary factor. This is represented by clothing which prevents the loss of heat from the body by preserving the medium of resting air that does not conduct the heat away from the body. It is for this reason that two or three coatings of thinner materials are of greater heat preserving value than a single thick coating, because the air is preserved in different layers. In facilitating the loss of heat the removal of one or more of those layers of clothing assists the cooling process by permitting radiation and conduction free course and also by permitting the vaporous air arising from the sweat to evaporate part of the heat. All of these expedient represent the voluntary element in the cooling processes. The heat production is governed also by direct voluntary action. During rest particularly during sleep the heat production is diminished, hence in the hot tropical countries men as well as animals lie down to rest during the intense heat of the day, this representing a physiological principle.

Heat production is also influenced by involuntary nervous action. Extreme cold produces a nervous shock resultingin muscular twitchings such as tremors, the result of which is the production of heat. When cold is applied artificially to the body there is an increased metabolic activity evident in the increased production of CO_2 and increased consumption of O. Curari given to a rabbit paralyzes the motor nerve endings withdrawing from the skeletal muscles influences that in normal conditions would have been stimuli to them. This indicates that certain impulses when unimpeded have important influences on the chemical processes taking place in connection with the muscles. Contraction in the case of a muscle has an important influence on heat production. If a frog is given curari and the gastrocnemius muscle is brought into contact with the resistance thermometer and stimulus is applied to the nerves that supply the muscle there is an increase of heat as long as the muscle contraction lasts. When the curari poison paralyzes the muscle and so prevents contraction there is no heat increase. From this it is concluded that a very important element in the heat production is the muscle activity as represented in the metabolism. Lœwy has stated in line with this that when the shivering condition produced by cold is retarded by the exercise of the will there is no heat increase. In the larger animals including man this is true, the metabolism depending largely on the action of the muscles and this activity being manifested in connection with heat production. In man his environment is subject to his own regulation very largely.

Lorrain Smith has pointed out that when the thyroid glands are removed the production of heat varies more according to external changes as in the case of a cold blooded animal, possibly because of the absence of the internal secretion in the body arising from these glands which has an important metabolic value. According to what we have said the muscles and glands represent the great heat producing centers. If the heat were

not constantly being eliminated from these the temperature would soon rise excessively in these parts of the body. Hence part of the function of the thermotaxal mechanism is to distribute the heat so produced in these centers throughout the rest of the body. In some structures as the bones, adipose tissues, cartilages and the cuticle there is only a very slight heat production. The circulation of the blood carries the heat over the entire body, while to a certain extent the principles of radiation and conduction account for a part of this heat distribution. This distribution does not take place with uniformity otherwise there would be an even temperature over the entire body. As we have said before the liver represents a higher temperature than the other organs and tissues of the body. This difference in the temperature of the different parts is due to the heat production as we find it taking place largely in the muscles. In the case of a dog weighing about 15.4 lbs. there is about 1.1 lbs. of blood: one fourth of this or .27 lbs. is found in the skeletal muscles and the circulation of the blood in those muscles occupies about ten seconds. This would represent about 360 times in an hour that the blood passes through these muscles, representing about 9,000 heat calories per hour or about half of the heat production per hour in the case of a dog. Pouring into the heart are two streams of blood at different temperatures at the venæ cavæ, these volumes of blood mingling in the heart. According to Heidenhain the right ventricle is slightly higher in temperature than the left, this representing the temperature of the cavities rather than that of the blood in the cavities. The right ventricle with its thin walls is heated by contiguity to the very warm liver, the heat passing by conduction through the seperating diaphragm, while the left ventricle is cooled by radiation in connection with the lungs. The blood is not cooled by passing through the pulmonary capillaries because the air has been raised to about body temperature before it reaches the alveoli. That the cooling does not take place in connection with the lungs has been proved in connection with suspended respiration and also with artificial respiration, both warmed and cooled. There undoubtedly is in connection with the heart an important heating process due to cardiac activity and this heat thus produced in the heart may be conveyed to the right side of the heart through the coronary venous circulation, so that the circulation when added to muscle activity accounts for the difference in tempearture.

The superficial temperature is taken as a general index of the loss of heat and the internal temperature as the index of heat production. If the superficial temperature is normal and the rectal temperature increasing then probably there will be an increase in heat production. If the rectal temperature is rising and the superficial temperature diminishing this may be due to lessened heat loss or to greatly lessened heat loss and at the same time gain through heat production. In connection with heat loss the surface of the clothing represents the real radiating surface, the skin unless unclothed not representing the radiating surface. This radiation is governed by physical laws depending on, (1) the difference in body temperature as compared with the temperature in the external medium; and (2) the coefficient of the emission of heat. The coefficient of emission according to Stewart does not vary very much in ordinary cases, the chief variation being found in the difference of temperature between the body and its environment. This variation in temperature may be modified considerably by clothing. Clothing is designed to keep the body heat from evap-

orating so that when heat is produced in connection with the oxidation of the food elements the heat is normally preserved within the body. It is important in connection with clothing to use materials that do not conduct heat freely both in winter and summer, because these represent the most efficient body protectors. Landois puts in order the conductors from the worst to the best, hare skin, down, beaver skin, raw silk, taffeta, sheep's wool, cotton wool, flax and silk when spun. In connection with heat radiation the heat is more easily radiated from a smooth than from a rougher surface. In regard to the absorption from the external medium such as the rays of the sun light colored materials absorb less heat and hence are cooler in summer than dark clothes. In regard to water and vapor evaporation and absorption linen clothing will absorb about half as much as woolen garments, the linen garment evaporating more rapidly. Hence woolen garments next to the skin are less easily moistened and they do not lose heat so quickly by evaporation, being for this reason better heat protectors in cold weather. Clothing therefore is a protection against excessive heat and cold so that it represents a physiological necessity.

In connection with the equalization of heat production and loss it is not possible to account for the heat produced and expended simply on the basis of the caloric value of food taken into the body and consumed by the tissues. In connection with this it is important to remember that water is produced within the system in excess of that taken in food and drink. Pettenkofer and Voit have proved that there is a large increase of water excreted in the case of severe muscular work, the increase continuing during the resting period of sleep. Even in case of abstinence from food it has been found that there is a steady water production. This takes place in connection with H oxidation, the H being taken from the tissues. Flint states that this H material taken from the tissues in water production is again given back to the tissues so as to sustain the equilibrium of the tissues. This water formation involves an important element in heat production. Here we have the fundamental principle which explains certain phenomena otherwise difficult to explain. Physical culture of the proper kind is known to have the effect of reducing an overplus of body fat. It is necessary for this that along with physical exercise there should be a diet consisting largely of solids with only a small percentage of fats and liquids. The physical exercise produces profuse respiration, thus eliminating water and increasing the heat production within the system. The exercise thus in connection with diminished fats, liquid and carbohydrates results in increased non-nitrogenous consumption within the body, resulting in excessive water production and the stimulation of the blood circulation. By this increased circulation particularly in the lungs and on the surface of the body there is a rapid elimination of the water which gets rid of the superfluous matter produced in the oxidation processes and equalizes the body temperature. The perspiration represents a continuous secretion in normal conditions being so slowly exuded as to be carried off rapidly by evaporation, called insensible transpiration.

Thus we may conclude that an increase in heat production may be induced by tissue activity chiefly in the muscles and glands. Resulting from this heat is imparted to the blood, resulting in connection with nervous stimulation in (a) accelerated respiratory activity which increases the amount of the air to be heated and thus takes up part of the surplus

heat; (b) dilatation of the cutaneous blood vessels, resulting in the exposure of a larger blood surface and therefore a cooling of the blood; (c) more rapid heart activity on account of which a greater volume of blood is thrown out to the surface of the body and air passages; (d) increased sweat excretion resulting in evaporation. If there is a lessened heat production on account of tissue inactivity the reverse of this is true in the case of these four elements in the balancing of heat loss and gain. This regulates the internal temperature, compensating for variations above or below the normal. By the dilatation or constriction of the cutaneous vessels stimuli are sent up to the various heat centers which result in the nervous regulation of the heat mechanism so as to balance heat loss by heat production and vice versa. The principal factors then in regulating body temperature belong to the department of expenditure and therefore represent (a) variations in the volume of blood exposed and cooled, and (b) variations in the amount of moisture that is allowed to evaporate; all of these taking place under the regulation of (a) the nervous centers, in connection with [b] the special heat centers, and [c] the vaso-motor, respiratory and sweat centers.

SECTION VI. Energy Income and Expenditure.

Generally the source of animal heat is the potential energy of the food. Very little is derived directly from the warmth of food or drink or from the external heat of the sun, so that these may be set aside as figuring very slightly in the income. The animal body is a mechanism for the transformation of potential into actual energy. The food furnishes the potential energy the body metabolism converting it into active energy in connection with the animal heat of the body and mechanical energy of the body in its external organs and external functional activity. The income of energy thus substantially consists of the oxidation taking place in connection with the food elements. The conversion of potential energy into actual energy may take place either directly or indirectly. Directly it takes place as a direct result of the processes of decomposition associated with alimentation, secretion and excretion; indirectly it takes place in connection with the mechanical action of the body involved in muscle contraction, the circulation of the blood, the action of the different organs and the external movements of limbs, joints etc.. The former represents the larger part of this transformation about nine tenths of the body energy being directly produced by chemical actions and reactions, one tenth depending upon the body activity In the transformation of potential energy into kinetic energy oxidation processes supply animal heat to the body and there is furnished a liberation of energy in the form of electricity and mechanical action. The larger part takes the form of heat. In muscle contraction four-fifths of the energy takes the form of heat and and one fifth represents activity which becomes reconverted in the body into heat again. The foods as we have seen enter the body system in the proteid, fat and carbohydrate forms and when oxidized produce urea, CO_2 and H_2O, together with certain extractive substances. During these oxidation processes the same result is arrived at in the transformation of potential to kinetic energy whether a series of changes take place or a single change before the final result is reached. The chief point in the energy production is the formation of the end products. For example the energy value of one gram of proteid is the amount of heat that is

evolved in connection with the complete oxidation of that one gram minus the energy that it wasted in connection with the urea that arises in the oxidation process. In this way estimates have been made by calorimetric observations of the amount of energy in the case of the different substances. It is estimated that one gram of proteid represents when oxidized about 8,080 calories; one gram of H oxidized yields about 34,460 calories; one gram of proteid represents when oxidized about 5,778 calories; one gram of fat about 9,300 calories; one gram of carbohydrate 4,100 calories. According to Ranke the normal diet consists of 100 grams of proteid, 100 grams of fat and 250 of carbohydrates, which roughly would give on a caloric basis 2,400,000 calories of heat. This heat supply is derived from the metabolic oxidation of proteids, fats and carbohydrates. By the O taken in through the lungs these food substances are oxidized forming CO_2, H_2O, urea and other end products. These food products are the products of certain processes in the plant and animal life in connection with the storage of solar heat. In their oxidation this solar heat is liberated and by the conservation of energy assumes a form that is suitable for body use. In connection with this law of the conservation of energy we find that none of the energy of the substance is lost, so that to burn the substance outside of the body would give practically the amount of heat liberated so that combustion within the body is practically the same in its results as combustion outside of the body.

From this standpoint estimates are made of the amount and character of the food and the amount and character of the wastes eliminated from the body; from these esimates are formed of the income and expenditure. Care must be taken however in these estimates as the proteid oxidation is not so perfect within the body as it is outside, as the urea formation represents an amount of energy thrown off which requires to be deducted from the total available energy from the nitrogenous food. In the case of the fats and carbohydrates as well as the proteids an oxidation equivalent is formulated which is taken as the average combustion value of the substances. The oxidation equivalent of one gram of meat free from fat is 5,641 Ca and of veal 5,660 Ca, in the case of muscle extracted with water Rubner estimates it at 5,778 Ca, of fibrin 5,511 Ca, egg albumin 5,579 Ca. The oxidation equivalent of urea is 2,523 Ca. As one gram of proteid gives rise to one-third gram of urea it is necessary to subtract 841 Ca from the oxidation equivalent of one gram of proteid in order to get its available energy. Speaking generally one gram of proteid represents from 5,200 to 5,800 Ca and if we deduct 841 from this it gives us about 4,300 to 4,900 Ca as the equivalent of one gram of proteid. In the case of fat meats the equivalent is 9,360, of butter 7,200 to 9,100 or as Stohmann averages it 9,312. One gram of starch equals about 4,123 Ca, Cellulose 3,692, cane sugar 3,866. The oxidation equivalent of one gram of fat therefore is about 9,300 and one gram of carbohydrates 4,100, the fat having a larger oxidation value than the carbohydrates. From a dietetic standpoint less fat is used because of the difficulty in digesting and absorbing it as compared with carbohydrates. Having the oxidation equivalent it is easy to estimate the interchangeable value of these substances, fats and carbohydrates being regarded as interchangeable. The ratio is one to 2.2, that is, carbohydrates may replace about half their weight of fats in the food. Rubner has made experiments in connection with determining the energy value of foods in animals, (1) by directly measuring in connection with the calorimeter the heat given off

from an animal in a day, and (2) indirectly by feeding on definite and known quantities of proteids, fats and carbohydrates and collecting the excretions so as to find what is destroyed and how much is destroyed. So accurate were the calculations of Rubner that the two methods gave practically uniform results. As the foods contain C, H, O and N and as the the end products are CO_2, H_2O and urea, it is easy to calculate the amount of energy. As we found above, only about one-tenth of the available energy assumes the form of work, hence, it is safe to regard for the present the entire energy as becoming heat. Hence, in estimating the income of energy we may find it out in four ways: (1), by estimating the amount of O used up; (2), by estimating the amount of C and H used in connection with oxidation; (3), from the composition of the food and its amount so as to estimate its combustion value outside of the body; (4), the amount of heat produced may be estimated by the use of the calorimeter. In connection with the last two methods recent experiments have been made very successfully. It is easy to find the amount of heat evolved by the combustion of any given quantity and quality of food. If the diet, therefore, should be as it is normally, 120 grams of proteid, 90 of fat and 330 of carbohydrates, we would have about 2,800,000 Ca, as the total heat production in a day assuming that complete digestion and absorption take place. In order to bring this to a regular normal we must deduct the proportion of undigested food found in the excretions. In connection with the calorimeter we get approximate estimates of the amount of heat produced and lost during a day by estimating for a part of a day. This, however, does not estimate correctly the income of the body because variations take place from day to day and even at different periods during the day, heat being acquired only at specific intervals in connection with the food, whereas, expenditure takes place continuously.

In connection with the law of the conservation of energy it is evident that the single cause of animal energy is the chemical processes involved in the oxidation of the food. This chemical energy assumes tow forms, heat and motion. As a given amound of chemical action produces a certain amount of heat and motion we can estimate the income. It is not easy absolutely to make such an estimate because the chemical processes in the human body are complex and these processes are accompanied by physical changes which require to be taken account of in estimating the results. The decomposition of substances chemically involves the absorption of an amount of heat equivalent to the amount that would have been evolved by a union of the chemical substances. In making the estimates, therefore, account requires to be taken of the combination and also decomposition changes. To get this external to the body the substances are inclosed in a calorimeter the rise and fall in temperature being marked as the basis of the calorific equivalent of the substance consumed. In connection with the substances of greatest importance a number of experimenters have determined their calorific value as follows: H 34,662, C 8,080, fat 9,686, butter 7,264, cheese 6,114, egg yolk 6,460, serum albumin 5,917, hæmoglobin 5,885, casein 5,855, blood fibrin 5,772, lean meat 5,724, cow's milk 5,733, hippuric acid 5,678, peptone 4,9,00, starch 4,479, maltose, glycogen, cane-sugar, cellulose 4,190, dextrose 3,939, urea 2,537, uric acid 2,741. The different food stuffs have different caloric values, the physical value depending upon the caloric. Danilewsky estimates the isodynamic value of food stuffs in relation to fats taking the fat as a standard at 100 grams, the others being, starch 220, grape sugar 250, cane sugar 236,

cellulose 221, peptone 201, meat extract 224. All of the caloric value is not taken advantage of as some escapes in the excretions. This is true of all the proteids, whereas, the fats and carbohydrates seem to be oxidized to their full value in the system. Rubner took a dog of about 26½ pounds. He gave it a definite amount of food and meat once daily, measuring the heat by the calorimeter and collecting the excretions including the CO_2 and H_2O, the dog resting absolutely so that no energy was expended as work. He calculated the heat production as follows: N excretion 3.06 Ca, C from fat 16.38, proteid 77, fat 201.5, total, 278.5 kilogram-Ca, as compared with a total loss of heat of 276.8 kilogram-Ca. Rubner regards the living body as a calorimeter so that as such it can be used in determining combustion values. In this way the experimental method can be tested and the results compared with what we find in connection with the combustion of the substances outside of the body. There are three methods made use of in these calculations; (1) Helmholtz was the first to balance the income and expenditure in the case of a human subject. The income he divided into three sources, (a) Estimating the expiration in connection with the amount of C necessary to produce the CO_2, 878.5 grams of CO_2 requiring 1,731,000 Ca. (b) The excess of O not appearing in CO^2 form used up in the oxidation processes in forming H_2O by uniting with H, 13.5 grams of H producing 318,500 Ca. (c) About 25 per cent not produced by oxidation representing heat derived from clothing, artificial heating, etc., in all 2,732,000 Ca. The expenditure of heat is found, (a) in the heating of the food taken, 2.6 percent; (b) in heating the air inspired, 2.6 percent; (c) evaporated in connection with the expiration from the lungs, 14.7 percent; (d) radiated and evaporated from the skin 80.1 per cent. Taking it that the energy is expended in the form of heat Vierordt estimates that there is a loss in the urine and faeces of 1.8 per cent, in expiration 3.5 per cent, by lung evaporation 7.2 percent, by skin evaporation 14.5 percent and by skin radiation 73 percent. (2) The Dulong principle based on the heat derived from the oxidation of C and H, these estimates being derived from the combustion of C and H outside the body. (3) The Frankland principle based on the oxidation of the actual food substances deducting the amount lost by reason of unused energy in the waste matters. Comparison of the results indicates that the second method gives simply an approximation to the true results, while the third is the method adopted almost universally, the heat values of an individual adult per day being estimated at 1,800,000 in the case of a minimal food supply to 3,780,000 in the case of a maximal food supply, in the case of very severe muscular exercise, according to Danilewski.

The heat produced in the body and in the organs of the body is distributed in part by the blood circulation and partly by the physical principles of conductivity. The law of conductivity applied to the body is that the amount of heat passing from one part of the body to another increases with the cross section of the tissue intervening the density of the intermediate medium and the difference in temperature in the two parts of the body. The loss of heat takes place from space to space by radiation and by the heat passing into a latent condition. The blood vessels containing a fluid that is normally in rapid circulation represents the great medium of the distribution of heat, the blood tending to equalize the temperature of the different parts of the body. Heat is lost from the body in connection with the respiratory process and in alimentation by the heating of cold food. Heat is lost from the body in connection with

the external medium in which the body lives. Several attempts have been made to estimate the amount of heat given off in an indirect way in connection with the body activities internally. This has been done by deducting the daily loss in connection with mechanical activity from the normal amount of heat income. Of 100 Ca of heat it is estimated that 80 percent passes of by radiation, 15 percent by evaporation, 2 and one half percent by respiration and 2 and one half percent in heating the food. Thus a large percentage is lost in connection with the skin indicating the important function of the skin in connection with animal heat. This forms the basis of hygienic conditions relative to clothing, as the wearing of warm clothing next to the skin prevents the rapid cooling of the body, thus maintaining normal animal temperature. To maintain the animal temperature is one of the physiological necessities of life in the case of the human subject so that the problem of animal heat is really that of balancing the heat loss. This is accomplished chiefly in connection with the circulation and the skin, cold lessening the heat loss by lessening the blood flow through the skin, diminishing the sweat excretion an thus lessening the amount of heat that becomes latent. Clothing that is a non-conductor of heat also prevent the loss of heat by keeping the warm air medium around the outer sur face of the body. The income and expenditure of energy therefore have an important relation to food and clothing.

HEAT PRODUCTION.—Among the ancients it was considered that animal heat had no relation to the physical and chemical laws. They regarded it as one of the vital qualities, this vital heat property being associated with the heart and distributed from the heart source in the circulation of the blood. The cooling process was accomplished by respiration whose chief function was supposed to be to cool off the heated blood and prevent too much heat accumulating in the body. With the progress of physical and chemical science a new theory arose. In connectiom with the process of fermentation it was found that heat developed and that by the relation of acid and base in the chemical reaction heat was also produced. Willis was the first to formulate the chemical theory that oxidation arising in connection with fermentation produces animal heat. A physical theory was then developed according to which by the friction of the blood corpuscles heat was produced within the vessels. At the same Mayow set forth the idea that the lungs performed the function, providing air in the form of O gas to the blood so as to generate in the blood heat. Later researches proved that CO_2 resulted from combustion. Helmholtz and his successors have shown in connection with muscle that chemical processes account for the production of heat, the exchange of material taking place in connection with the food, respiration and excretion, this chemical decomposition going on constantly in the animal body.

An important addition to our knowledge on this subject arose in connection with the law of the conservation of forces. Physiologists applied this principle to the production of heat and its utilization in the heating of the body and in connection with the expenditure of animal force. Potential energy belongs to matter either as a property or stored within it in some way so that it is capable of transformation. From this standpoint the animal system represents a storehouse of potential energy. When O is united with the tissues oxidation follows and heat is produced. When a body is oxidized heat results. To measure this force the entire body would need to be burned in a calorimeter, the amount of heat produced representing the caloric potential value of the body. The body contains,

therefore, stored in its tissues potential energy and this potential energy is liberated when O comes to the tissues for oxidation. The food, therefore, represents an important element, because when food is absent the body substance itself is decomposed in the liberation of energy. Here we have the basis both for heat and force production.

Having discovered the fact that oxidation does produce energy the next question is where is the seat of oxidation. Mayow who first formulated the oxidation theory said that it took place in all the tissues of the body. Lavoisier regarded the lungs as the chief seat of the changes minor changes taking place in the other organs and tissues of the body. Others concluded that it took place in connection with the capillary circulation, the variation in the arterial and venous blood temperature forming the basis of this theory. Others have objected to these theories on the ground that if the oxidation took place in especially localized areas the tissues would themselves be burned up in the process.

Berthelot has proved that in a combination of O and Haemoglobin in the lungs heat generation does take place to a slight extent in the lungs. This represents only a slight heat production compared with the combination of O and C, these producing about seven times the heat produced by the combination of O and H, so that according to recent results, of the O taken into the body in respiration one seventh is oxidized in the lungs in connection with haemoglobin in the formation of oxy-haemoglobin; six sevenths is oxidized in the tissues in connection with the tissue oxidation. In heat production then we have this starting point, namely the division between the oxygen in the lungs and the oxygen carried to the tissues. In the case of the muscles as we have seen the largest heat production takes place in them so that they are the principal source of the heat. During muscle activity the heat is increased in the body while there is an increased heat loss. The larger proportion of the body consists of muscle, Bernard estimating that in a dog almost 47 percent is muscle, bones being about 20 percent. In the case of the removal of the muscles from the body and artificial stimulation there is a production of heat. Aside from this artificial production the muscles are normally during rest as well as during activity the chief seats of heat production. When the muscles are taken from the body they preserve the power of O consumption and CO_2 elimination. Bert in his experiments has shown that muscle absorbs about 50 cc. of CO_2, and discharges 56 cc. of CO_2, the brain, kidney, spleen etc. absorbing and discharging a relative smaller amount of O and CO_2. This exchange depends upon the temperature being increased by a rise in external temperature and decreased by a fall, there being a limit to the rise and fall. Regnard points out that when the external temperature is raised about 40 degrees instead of there being an increased interchange of O and CO_2 there is a decrease in the exchange. Hermann objects that some of the CO_2 arises in connection with the development of post mortem bacteria. This has been answered by Tissot who took care to render the muscle aseptic after excision finding that there is O absorption and CO_2 discharge. The tissue respiration then involved in the muscles represents an important source of heat, muscle when active being very much more free to absorb O and discharge CO_2. If the muscle activity is suspended from any cause the temperature of the body is lowered. Curari given to animals suspends muscular activity, affecting the motor without affecting the sensory nerve connections, resulting in a fall of temperature and a diminution in the respiratory exchange of gases in the tissues

which does not increase, or increases only slightly, the exchange even when the tissues are artificially heated. When artificial respiration supplies fresh O the venous blood still remains oxygenated. In the case of the administration of anaesthetics by which muscular activity is lessened thereis also a lessened respiratory muscle exchange, MacAlister claiming that the muscles become fatigued more readily in producing heat than in active work, so that by loss of heat the heat production is lessened. Muscular exertion applied to the muscles in general increases the temperature of the body. The heart muscle is very active in the production of heat, different physiologists having formed different estimates, Foster claiming that the work done by the heart represents 60,000 kilogrammeters or about 138,249 Ca per day.

In connection with the glands we find also very active chemical changes associated with heat production. When the glands are active there is a greatly increased blood supply and this increase of blood often prevents the increase of temperature from being noticed. Experiments have been made, aside from the liver which represents the most active of the body glands and therefore the warmest part of the body, on the sub-maxillary gland. When the gland is very active the blood volume is increased in the gland. Ludwig in connection with the use of the thermo-electric needles found that the secretion of the sub-maxillary gland is from one to one and onehalf degrees warmer than the blood of the carotid artery. Bernard by ligaturing the blood vessels of the gland found that on exciting the chorda tympani there was a rise of temperature, whereas on stimulating the sympathetic there was a fall. These are regarded as evidences of the temperature nerves. Bayliss and Hill recently in connection with their experiments concluded that the gland temperature represents a temperature about equal to that of the blood in the aorta; the gland and the tissue around the gland represent a heat slightly greater than that of the saliva and from this they say that no heat production takes place directly in the gland. On stimulation to activity there is an increase of heat accompanying increased salivary secretion, but that when stimulated in connection with the chorda tympani there is not an increase of the salival temperature. Bernard states that in connection with the intestines there is a slight heat formation, the blood coming from the intestines being higher in temperature during the digestive process, the blood found in the portal vein being about .3 of a degree warmer than the blood in the abdominal aorta. When the splanchnics are stimulated there is no increase or fall of temperature and the same thing is true of the stimulation of the vagus. The brain is undoubtedly a source of heat for the temperature of the brain is above the temperature of the arterial blood that passes to the brain. It is however only a very small producer because the blood circulation is small in quantity and the changes are not very active as compared with the other parts of the body. There is no doubt that activity in connection with the internal organs of the body produces heat but that it is claimed by some is so slight as to lead to the conclusion that none of these organs are heat producers.

Lavoisier concludes that the heat production can be accounted for in connection with the oxidation processes. The experiments of Rubner have set aside this extreme theory. The heat of the body is estimated according to Rubner from the combustion value of the food stuffs and also from the size of the body surface and the activity developed in connection with muscular and digestive actions. In regard to the relation of the

superficial surface to heat production it is claimed by Langlois that in children the heat production varies with the skin surface, In connection with the combustion processes of the body of course there is a heat production, the amount of this heat production being generally estimated from the respiratory interchange. This does not give with absolute accuracy the heat production because the respiratory interchange does not represent the amount of combustion taking place, as there may be a storage of O and the CO_2 may represent the oxidation of this stored up O. From this standpoint even when free O is not supplied to the tissues there is is still an exchange going on because the stored up O is drawn upon. If the observations are extended to a longer period this objection may be overcome by estimating the average interchange. Lavoisier's experiments led him to conclude that at least in the case of a human subject when the temperature falls there is an increase in the O consumption and CO_2 excretion and when there is a rise in temperature the O consumption and CO_2 excretion are decreased. Pfluger has made a large number of experiments in order to test the effect of changes of external temperature in connection with the respiratory interchange. From these tabulated results it is evident that there is a decrease in the respiratory interchange when the external temperature is raised up to the point represented by about 37 degrees, when with the increase of metabolism the respiratory interchange increases. The change is more sudden in the lower and smaller animals than in man. This interchange is characteristic of all forms of life for even in the vegetable life there is an oxidation process which results in the production and storage of heat. In the lowest of the animal forms of life there is heat production, even in the case of a frog where the body temperature may be lower than the external temperature we find this heat production. In most of the cold blooded animals we find a temperature slightly higher than that of the surroundings whereas in the warm blooded animals we find a still further increased production of heat. As we rise in the scale of animal life from the cold blooded to the warm blooded animals we find that the increased production of heat follows this change. The homaiothermal produce more thon the poikilothermal, but it varies among the two classes in the different species of animals, depending largely if not altogether on the relative respiratory action. Reichert believes that every individual whether animal or man has his own specific heat coefficient representing capacity of heat formation to body size whatever the nature of the animal may be. The only general principle that can be laid down is that according to the respiratory activity measured by the O consumption we find that heat production takes place.

The production of heat depends very largely upon conditions and circumstances. The younger animals produce a greater amount of heat from their size and weight than the adult or the old. This is largely due to the amount of metabolism taking place and also to the size of the body surface, the body surface being larger for the weight in the smaller as compared with the adult. Where the animal is immature or feeble the heat production is lessened. The body weight is important chiefly in regard to the size and the volume of the tissue structures that are actively engaged in metabolism such as muscles, glands etc. compared with bone, cartilage etc. that are less active. The weight does not determine the heat production because animals of equal weight may produce different quantities of heat. Other circumstances may produce a variation, for ex-

ample an animal that is very fleshy will produce more heat on account of the presence of a large flesh structure compared with an animal that is lean or one that is stout on account of a large proportion of adipose tissue. In connection with the circulation we find that increased circulatory activity produces more heat on account of the larger supply of blood which is associated with increased metabolism. The increased circulation also determines a large quantity of blood to the surface of the body so that as radiation takes place from the skin, impulses are set up that tend to excite the thermogenic centers. Accompanying circulatory activity is respiratory activity and sweat excretion increasing the loss of heat and creating a demand for more heat, the demand regulating the supply. Along with this increased circulation there is an increased cardiac activity which generates heat. When the internal temperature of the body is raised there is an increase in metabolism producing more heat. The external temperature also influences the heat production although to a less extent in warm blooded than in cold blooded animals. In the case of the warm blooded animals the amount of heat produced is inversely proportional to the temperature of the external medium so that as the external temperature becomes cooler there is a stimulation on the surface of the body to heat production. As a result of this, in frigid countries and in colder seasons there is a greater heat production because of the stimulation brought to bear upon the thermogenic centers. The kind of food has an important influence on the amount of heat. This is apparent when we consider that one gram of fat yields almost twice as many Ca as one gram of proteid and one gram of carbohydrates slightly less than one gram of proteid. It is for this reason that fat in colder countries is a very efficient heat producer. It has been claimed by some physiologists that in the production of heat there are diurnal variations corresponding with the variations of the body temperature. This has been explained by the production of heat which is necessarily greater during activity than during rest. On this basis of activity it has been estimated that during the day when awake the heat production is about three times that during the night when sleeping and that during the day if active there is an increase from one to one and one-half times as compared with a resting condition.

The ultimate source of all heat as we have said is the chemical change in connection with the food. Rubner has calculated the heat production in the case of different classes of men, taking as his standard about 147 and one-half lbs. In the case of a man deprived of food the heat production daily represents 2,303,000 Ca; in the case of brain workers such as official men, teachers etc. it is 2,445,000 Ca; in the case of active workers such as soldiers during peace and laborers it is 2,868,000 Ca; in the case of skilled mechanics who follow their mechanical occupations it is 3,362,000 Ca; in the case of miners who are supposed to have hard work under hard conditions it is 4,790,000 Ca; in the case of workers who have to bear the elements of the weather, like the railroad laborers and street workmen it is 5,360,000 Ca. The rate of production of heat therefore may be said to be determined by a number of circumstances. (1) It depends upon the metabolism in the case of the individual. In the case of two individuals of equal size one has greater metabolism than the other so that the body substance is used up in the production of heat. As we said every species and even every animal has its own individual coefficient. (5) The larger the body usually the production of heat will be greater, because in

the larger body there is a larger number of heat producing elements. This however is limited because there is a greater heat loss in the smaller body relative to its size, so that to compensate for this loss the smaller body must produce more heat for its size. Therefore the smaller body relatively produces the larger amount of heat on account of "the struggle for existence" as Foster says which throws on the smaller body the greater volume of loss requiring a higher individual coefficient. (3) The taking of food increases the heat production, this heat production being still further increased in connection with the process of digestion. In the dog the heat production increases after a meal until the maximal heat temperature is reached from the 8th to the 9th hour after meal, after which it falls again to the lower level. (4) Muscular exercises has an important influence in heat production. This include the muscle contractions, organ activities and locomotive exercise of the body. The greater the body activity therefore the greater is the heat production. (5) Variations in the amount of heat actually produced in the body also influence the temperature regulating the production of heat. This is accomplished through the stimulation imparted to the nervous system. When the impulses are aroused on the peripheral surfaces or in the internal organs these are sent to the brain and spinal centers producing thermogenic and thermolytic activity which increases or diminishes the heat production. (6) As the temperature of the body is maintained uniform normally this is sustained by equilibrium between heat produced and the heat given off so that if the heat loss is lessened there must be a storage of heat in the body. The loss of heat is regulated principally in connection with the external surfaces of the body. When this loss is prevented storage may take place under the influence of the skin externally stimulated so as to prevent heat radiation. Under vaso-constriction influences the vessels of the body become constricted as in the case of blood transfusion or in the case of sudden removal of water from the body on account of the lessened volume of blood which is therefore driven into a smaller space. This storage is limited because if the heat is stored so as to increase the body temperature above 6 degrees C over the normal death results. This high temperature seems to produce a molecular dissolution resulting in the disintegration of the elements involved in the body substance.

HEAT LOSS.—An animal may lose heat in various ways, the loss being controlled largely by the skin and the lungs. Heat expenditure may be classed under three heads, if we omit its expenditure in connection with work which we will discuss later. (1) The amount expended in warming the ingesta. The food drink and O are cooler than the body and when they enter the body organs they are warmed. (2) Conduction and radiation. By these processes a certain amount of body heat passes into the medium surrounding the body. When the medium is colder there is a greater heat loss, especially if the medium is damp or moist; the same thing is true if the medium is in motion. (3) Evaporation, which takes place either through the skin or respiratory passages, the former depending on the temperature of the surrounding air and its degree of moisture or dryness. Vierordt has estimated this loss in connection with (1) The urine and faeces, (2) the expiratory process, (3) evaporation in connection with the skin and lungs, (4) radiation and conduction from the skin surfaces. The two main sources of heat loss are radiation and conduction and evaporation.

(1) Radiation and conduction. The quantity of heat lost by radiation

and conduction is normally proportional to the difference between body temperature and the external temperature. When the skin is warmer and the external temperature is colder the loss will be greater. Skin heat is regulated by the superficial circulation which is regulated by the vaso-motor system. When the superficial vessels are constricted the circulation is diminished the skin becomes cool, these results being associated with a cold environment. If the external temperature is high then the vessels distend, the circulation increases and the skin becomes warm. Here we have the principle of the demand regulating the supply of heat. In the human subject the outer skin layer and the subcutaneous adipose tissue are not good conductors of heat. By the clothing a protecion is afforded so that the contact of the skin is not with the external temperature but with a generally regular medium of air. As this air is resting and stationary less heat loss takes place than if it were in motion.

Parry found that he and his associates could more easily stand a cold that would freeze the mercury if the air was quite still than in the case of a higher temperature if there was a wind. In addition to this moist air is a better conductor of heat than dry air, hence if the air medium next the body is kept in a dry condition the loss of heat is much less. In the case of the whale or seal we find a thick covering over the body so that they can mantain a high temperature even in the frigid zone. In the greyhound we find the opposite condition the fur being light and scarce and the skin thin so that at the least cold it shivers. The extent of this loss by radiation and conduction in connection with the skin has been estimated by Vierordt in the case of an adult as 73 percent of the entire heat loss in connection with the body estimation being made of the loss during 24 hours. The amount of heat lost by radiation can be measured by means of a thermopile or a resistance radiometer. The radiometer is similar in principle to the resistance thermometer used in measuring superficial body temperature. It consists of a tin-foil grating fixed inside a box to prevent draughts from affecting it. There is a sliding lid to the box which is kept closed till observations are made, when it is opened and part of the skin is applied to the opening at a distance of five or ten cm. from the grating. The radiation intensity is measured by the excess of the temperature of the radiating surface over the surrounding medium. The portions of the skin uncovered radiate more than the covered parts per unit of surface area; and the warmer parts as the forehead radiate more than the cooler parts like the ear. If the individual is at rest radiation is greater than conduction in the case of an active and working individual. The more rapid the air renewal takes place in connection with the skin or clothes the lower is the temperature of the radiating surface and there is greater heat loss to the adjoining parts by conduction and smaller loss by radiation to the object in proximity to the person. (2) Evaporation. Franklin first suggested that in connection with the excretion of sweat there is a heat evaporation that keeps the body normal in temperature. This was proved by others in connection with dry and moist air, dry air not affecting the body temperature, even dry air 125 degrees, whereas moist air produces a rise in temperature. According to Ludwig about 20 percent of the daily loss is due to evaporation in connection with the skin and respiratory organs. Waller estimates that the following parts of the surface of the body represent the changes taking place—palm of the hand 24 milligrams per 20 sq. cm, sole of the foot 14, forehead 12, cheek 6, axilla and popliteal space 10, forearm and leg 5 at an external temperature

of 20 degrees. The loss of heat by evaporation of water in connection with the skin can be easily found by getting the amount of water lost. Taking the average loss of sweat daily as 850 c.c. this will represent about 461,750 Ca, one gram of water representing about 555 Ca in its conversion into vapor at the normal temperature. In connection with the lungs there is also a loss partly by evaporation and partly by heating the expired air, the evaporation representing about 15 percent of the heat loss and the heating process of air about 2.5. The loss through the lungs may be estimated by the weight, temperature and specific heat of the expired air in connection with the water excess found in it in the form of vapor over inspired air. Helmholtz estimates the amount of heat required to warm the expired air to body temperature at 70,000 Ca and the amount required to evaporate the water excretion from the lungs 400,000 Ca so that the total lung loss would be about 470,000 Ca.

All the conditions that affect heat have a bearing on heat loss, for example, age, sex, fatty or lean body condition etc. . There is a greater heat production and also loss in the young than in the adult for relative body weight, because of the larger relative metabolism and the greater body surface relatively. Sex does not influence heat production materially although most physiologists claim that relatively there is a greater heat loss in the male than in the female, because of the greater amount of subcutaneous fat in the female as compared with the male. In different species of animals great difference is found due to the medium in which the animal lives, the habits of life etc. There is a greater loss of heat in the homoiothermal than in the poikilothermal animals because of the greater heat production. In the case of an individual with a larger or smaller proportion of subcutaneous fat there is a difference because subcutaneous fat is a bad conductor of heat, therefore where it is large the heat loss is retarded. It is for this reason that fowl living largely in cold water have a great abundance of this fat. To use grease even on the external skin surface prevents radiation and this is frequently used by swimmers to guard the skin surface and to retain in the body its normal heat. Where the water and air are of equal temperature exposure to water involves greater loss of heat because the water is a good conductor. Still there is a greater heat loss in the dry than in the moist air, because the dry air assists the excretion of sweat and the lung evaporation. Cold dry air is unfavorable to heat loss because it does not assist the vaporizing of the water and if the cold air is moist it tends to draw off the heat. Heat loss is largely regulated by the clothing whether natural fur as in animals or artificial coverings of the skin. From a hygienic standpoint the worst conductors in the form of clothing represent the warmest, hence fur and wools of different kinds are freely used to prevent heat loss in cold climates. The coefficient of radiation will depend on the coefficient of conductivity of the materials used and also on the radiating nature of the surface of the skin and the surface of the clothing. To prevent loss of heat a fine and smooth cloth is perferable because a coarse cloth is a good radiator and conductor of heat. In the case ot underwear, clothing that has a large moisture absorbing and retaining capacity is most advantageous, preventing too sudden evaporation and thus protecting against chilliness. The increase of the internal temperature of the body also assists heat loss. This is due to the fact that when heat production is increased the system attempts to throw off some of the excessive heat. In this attempt there is an increased circulation throwing out

a large amount of blood to the surface of the body where it is cooled; at the same time respiration is increased, a larger amount of air respired assisting in the heat loss. When the internal temperature is higher than the external temperature radiation and conduction are assisted. Hence, the external temperature aids in heat dissipation, heat in contact with the body surface exciting sensory stimulation to lessen the production, while cold increases both the heat loss and production. The greater the amount of heat produced the greater is the amount of heat lost unless when body temperature gets below the normal, when heat loss remains steady and heat production is increased so as to raise the body to its normal temperature. The size of the body has also an important influence on heat loss, the larger the body surface the greater the loss so that as a larger animal has a greater surface it has also a greater loss. The body surface however is not constant as a radiating surface. In the case of a lifeless surface the coefficient of radiation is constant but in the case of a living body there are variations depending on, (1) the conductivity as affected by vascular changes; (2) on thickness of the skin which is an important variation among different individuals and races and even in the case of different parts of the body; (3) on external circumstances such as clothing, temperature etc. By the contraction of the erector muscles in connection with the hair follicles the tensity of the skin is increased, the blood vessels are constricted and the blood flow is diminished so that the coefficient of heat loss is lessened. This is of importance in the case of animals whose body is covered with fur as is indicated by the fact that the removal of the hair from the skin in the case of a rabbit will result in death, even if the temperature externally is kept high. If the sebaceous excretion is increased the coefficient of heat loss is diminished because the accumulation of fatty substances retards heat radiation. Ordinarily in sweating however as in the case of bathing the coefficient is raised.

SECTION VII. Heat Production and Loss in Relation to Work.

One of the ultimate purposes of food is to supply the body with energy for work. The latent energy found stored in the food is liberated as kinetic energy and kinetic energy represents mechanical force. Force represents the manifestation of energy. In the case of a body the force is represented in connection with change of position. Inanimate bodies being of themselves inert and having no tendency to pass from rest to motion anything that will produce this change from rest to motion or from motion to rest in the physical sense is force, the former being force and the latter resistance. Hence the attractions of molecular bodies are forces. The muscular activity of men and animals represents force. This represents the activity of respiration, circulation, mechanical movement and work. From the stand point of physics force or kinetic energy and heat are interchangeable. In elevating a body to a certain height force is imparted to it as potential energy equal to the force used up in falling to the ground again. If this force could be given to another body of the same weight this body would be elevated to the same height as the first body. The amount of this force is spoken of in connection with the unit of work as the kilogram-meter or the foot-pound. In the case of a body of definite weight falling to the ground through a definite space a definite amount of heat is generated which can itself produce force so that the

heat unit is said to produce a certain number of the work units. As we stated before six-sevenths of the energy of the body represents heat and one-seventh force. This represents more than the proportion of force developed in connection with a steam engine. Of the heat produced by a steam engine only one-eighth or one-ninth can be utilized as working force, hence the body is a more perfect working machine than the steam engine and more delicately adjusted to work. In the case of the animal body voluntary effort can utilize more than in the case of the inactive steam engine, unless when as in exhaustion from fever the energy is converted into heat and for this reason can not be available for force. In connection with the normal healthy individual adult it is estimated that the normal force represents about 3,400 foot tons or 1,054,000 kilogram-meters. (One foot pound equals .1381 kilogram-meters; one foot-ton equals 310 Kmg.) Of this full amount of energy about one-seventh represents the amount expended in the motion and locomotion of the body without any special work, the balance being used in connection with body temperature. In the production of this energy the different food elements are necessary. If we take away O death will follow in a very short time; if water is withheld the body may survive some time but fatal results will follow inside a week; if the other food elements are not provided the body will exhaust its own substance in the production of energy and then yield up its own existence. The food equivalents and their heat equivalents have been already discussed in connection with heat production, the unit of measurement being the calorie, one Ca being equal to 1.53 foot tons.

Estimates have been made of the motion and force producing value of foods, this force value being estimated in connection with soldiers, hospitals and schools in which large numbers of persons in health and sickness are provided with common rations. By comparing the force producing value of foods as found in the chemical laboratory with the results in connection with work and the elimination of waste matters, these results are obtained with approximate accuracy. These experiments and their results are useful in enabling us to estimate the normal diet of a working adult. The following are based on the caloric energy yielded by one pound of the material—butter 3,615 Ca, lard 3,570 Ca, fat pork 3,500 Ca, chocolate 2,650 Ca, sausage 2,065 Ca, ham 1,960 Ca, crackers 1,900 Ca, sugar and barley 1,800 Ca, oat meal 1,850 Ca, tapioca 1,820 Ca, cornmeal 1,644 Ca, flour 1,644 Ca, beans 1,615 Ca, cheese and milk 1,600 Ca, beef 1,460 Ca, dried apples 1,418 Ca, potatoes 375 Ca, Cabbage 155 Ca, oysters 230 Ca. An adult doing a normal amount of work uses as food 120 grams of proteid, 90 of fat, 330 of carbohydrates, 744 of air by respiration, 2,818 of water and 32 of salts. The entire weight is about 7 lbs. or one-twentieth of the body weight. According to this standard the body transforms about 6 percent of the water and fat, one percent of the proteid, .4 percent of the salts daily. According to the Kensington Dietary the percentages of food to sustain normal working force are; water 81.5 percent, proteid 3.9, carbohydrates 10.6, fats 3, salts .10. Water as a force producer is of little value, although part of the water is ~~split up~~ and used in connection with other compounds and water is formed in the body by the union of O and H arising in connection with some of the chemical processes. Salts have no force producing power but they are used in connection with tissue formation and repair, especially in the bony structures of the body and as these bony structures represent an important element of strength they may be regarded as force producers. Sulphur and phos-

phorus are also useful in force production especially in the phosphorized compounds. The proteids, fats and carbohydrates are sources of force production, the values of which we have already discussed. During work, especially severe work the proteid and carbohydrate consumption remains almost unchanged, whereas the fats are consumed in very large proportions, when the fats are absent from the food these fats are produced in connection with the proteids and carbohydrates. The fats are necessary in the production of heat and in the upbuilding of muscle and nerve which are essential in mechanical activity. The standard diet in the case of a healthy adult during normal work is estimated at 20 grams of N found from the proteid of 120 grams and 320 of C found in the fats and carbohydrates, a ratio of N to non N of one to 16, or a ratio approximately of one to 3 and one-half in the case of animal and vegetable food. In muscle contraction the glycogen supply is used up so that this must be provided in carbohydrate form; when exercise increases the growth of muscle there is a further demand for nitrogenous food to build up muscle tissue. C and H compounds oxidize slowly and therefore yield a more constant and continuous supply of energy so that these substances as found in connection with fats and proteids are essential for the muscular activity of the body. The energy accumulated in the body system is expended in locomotion and muscular work, in respiratory and vocal movements. All the internal work of the entire bodily system together with the external work of the body, mental activity and cardiac actions unite in the expenditure of this energy. An average day's work including exercise is estimated at from 150,000 to 250,000 kilogram-meters. Older physiologists estimated that all the nitrogenous food went to the upbuilding of the tissues including the muscles and that the nitrogenous waste arose from the metabolism of the body in its separate organs, the non-nitrogenous being used in connection with heat, respiration and work, the excess being stored up as fat. This view however as we have seen requires modification the muscle tissue not being supplied solely by the proteids but by other substances and the muscular activity depending not only on proteid nutriment but also on carbohydrates and fats. As we said before not only do the muscles feel the drain of labor, the circulatory and respiratory system and in fact the whole body is drained by active muscular exercise. The urea as we have seen is not necessarily increased by severe muscular exercise. Certain conditions may arise in which such an increase does take place. The muscular energy must therefore draw upon some other source than proteid metabolism. It is estimated that work for one hour will cause a five-fold increase of the CO_2 eliminated compared with the ordinary resting condition. In comparing heat and work the heat unit may be transformed to the work unit by multiplying by 424.5. During the sleeping condition the activities in actual exercise are the heart and the inspiratory muscles. The entire cardiac activity may be estimated at 88,000 kilogram-meters daily, the work of the respiratory muscles 14,000; all this work is converted to heat in meeting and overbearing the resistance found in connection with the circulation of the blood through the body. If we add to this the mechanical equivalent of 8 hours of work at 27,000 kilogram-meters an hour we would get a total of 318,000 Kmgs. This would represent about 750,000 Ca as the amount of energy expended by the body internal and external in a day's work. In a day there is added to the available energy from heat about 2,500,000 to 3,500,000 Ca which would represent about 3,250,000

to 4,250,000 Ca in a day. If the human organism were exactly like a machine there would be a smaller amount of heat formed in the body during work because more is expended. The human body however produces less heat from the potential energy when work is done, much more energy is used up in the body although this may be compensated for by the results both in increased heat and increased work.

Hirn cites his own experience in connection with the relation of heat and activity. When passive he absorbed 30 grams of O per hour producing 155 Ca as measured by the calorimeter. While in the calorimeter he performed work which he represents as equivalent to 27,450 Kmgs., absorbing during the performance of the work 132 grams of O and producing only 251 Ca. This indicates the working capacity of the human system showing that by increasing the work within definite limits heat may be produced in excess of the needs of the body, while at the same time transforming a large proportion of the heat produced into mechanical activity outside of the body. Whether the chemical energy is first formed into heat and then transformed into work, or whether the transformation takes place directly to work we do not know. It is supposed by some that chemical energy is first changed to electrical energy and that this electric force in stimulating the muscle and nerve in connection with the production of work is used up and in part converted again to heat in the muscle. Some claim that the chemical energy is transformed directly to muscle activity, alleging in proof of this that under certain conditions the muscle is cooled rather than warmed during contraction. This however would not of necessity follow because the cooling might be a result of interaction between the physical and chemical changes without involving the direct transformation to activity.

SECTION VIII. Pathological Temperature of the Body.

We have allready referred to the incidental changes involved in a rise of temperature. Pathological temperature is interesting from the standpoint of fevers and the post-mortem condition because these represent physiological conditions. (1) Fevers. Fever represents a pathological condition usually arising from the presence and action of bacterial products that produce a rise above the diurnal variation. Associated with it is usually an increased heart and respiratory rate and an increased urea excretion, with a lessening of the CO_2 and alkalies found in the blood. In the light of the discovery of the thermogenic centers it is claimed that the poisonous substances originating in connection with the bacteria stimulate the centers to activity resulting in heat production. It is to antidote this that antipyretics are given with the object of lessening the center activity and so preventing the accumulation of heat either by eliminating the poisonous substances or counteracting their action. It is claimed in support of this that if the basal ganglia are suspended, by dividing the pons from the nerve connections below the brain there is no possibility of producing a fevered condition of temperature by the use of the bacteria culture, such bacteria producing fever in a normal animal. In such a case where the basal ganglia are cut off antipyrin has no effect on the temperature. It has been objected strongly by Schaefer and others that no heat centers exist and hence no such action can take place. Mosso has found that by the use of cocaine injections there is a marked rise of temperature and the same kind of fever is found when animals are

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paralyzed as the result of curari, cocaine injections being used. This it is claimed indicates that there is a nervous fever arising from the greatly increased nervous metabolism. This however overlooks the fact that curari poisoning does not paralyze all the tissues of the body but simply those of motion, the heart and the involuntary muscles remaining still in active connection with the central nervous system. It has been found, however that in certain cases where the muscles are paralyzed by curari no rise of temperature is found as indicated by the rectal temperature. This seems to indicate that the fever in the normal animal under the influence of cocaine is purely muscular and not a mervous fever or at least that the action of such a substance as cocaine is indirectly through the central nervous system. It is certain that some of the antipyretics act at least directly upon the tissues, such as quinine affecting the heat producing tissues, whereas antipyrin affects them through the central nervous system. This fevered increase of temperature is always associated with some other variation from the normal in the body system; and that the fevered condition may be found without any increase in temperature and even with a fall in body temperature indicates the difference in cause. Here however we do not consider those other pathological conditions.

It is possible that variations between heat production and loss may occur in different ways. Normally heat production and heat loss are about equal but both are normal. Both heat loss and production may be abnormally increased or decreased. Heat production may be normal while there is an abnormal diminution of loss, or heat production may be abnormally increased with a slightly less abnormal heat loss or a greatly diminished heat loss. Frequently both lessened loss and increased production are involved. The standard of heat production and loss is that of a normal individual resting. In cases where the heat production is low and the respiratory interchange in the muscles is also low this does not represent such a great deviation from the normal. These however do not explain fully the fever temperature. Merely increased temperature cannot explain fever because in cases of very severe exercise there is very much increased metabolism and yet the variation in temperature is only slight and transitory in case of health. The fever temperature therefore must be due to some disordered condition of the body mechanism so that the variation of heat production and loss can not be regulated and compensated for as in the normal healthy body condition. This involves therefore a derangement of the regulative mechanism, this disorder continuing only so long as the variation in temperature is found. After the maximum is reachen the regulative mechanism becomes again adjusted on an abnormal standard representing a higher level. Rosenthal by the use of the calorimeter found that with an increasing temperature during the earliest fever stage there is a retarded heat loss. When the fever reaches its maximum there is sometimes though not always an increased production of heat. When the crisis is reached and after the fever begins to go down there is a gradually increasing loss of heat. Various views are held in regard to the producing cause of the increased metabolism. Some regard it as the result of the rise in temperature. This however has been clearly disproved by experiments, for example, in fever there is a much larger increase of urea formation and excretion than could be accounted for by artificially raising the body temperature. This large urea excretion is not parallel with the increase of temperature in fever, being more char-

acteristic of the stage following the crisis so that while the fever is subsiding there is an enormously large urea excretion. Cases are reported in which on the 3rd or fourth day after the crisis took place three times the amount of urea is excreted that would be found in the normal healthy individual. Artificially produced fever by the injection of bacterial poison increases the respiratory interchange of O and CO_2 even when efforts are made to keep the body temperature from rising. This seems to demonstrate that in fever conditions one of the primary phenomena is that of increased metabolism.

If this is so then the question arises, is the temperature increase anything more than an accidental symptom of this increased metabolism. The older view was that the increase of temperature represents a necessary and important part of the pathological condition, one of the primary factors in the fever and to be reduced if at all possible. It is undoubtedly true that in certain cases where the fever temperature is excessively raised the rise in temperature, say from 106 to 111 degrees, represents a true pathological condition dangerous to life. Bacteriology however suggests that the increase in temperature represents rather a symptom which gives evidence of the attempt of the regulative heat mechanism to protect itself, than a primary condition of pathology in the disease, the increased heat arising rather as a curative means of destroying the bacteria or bacterial poison. It is claimed that the erysipelas germ lives only between the temperatures from normal to 39 degrees and that above 39.5 degrees the influence of the heat is to destroy the baccillus. In the case of the baccilli anthracis and the pneumococci a temperature of 42 degrees producs enfeebling so that instead of producing the pathological condition they render the animal immune from the disease. These bacteriological principles are confirmed by clinical experience where an increase of temperature seems to give the patient a better hope of recovery from the disease. In this case, at least in some of the fevered conditions, the increase of temperature represents a physiological not a pathological condition, in other words it represents the attempt of nature to restore the normal and establishes the principle that nature has always a tendency to return to the normal. While fever represents a disorder of the heat regulation it marks rather a symptom of the disordered condition in the increased metabolism, the heat condition representing a disturbance of the regulative heat mechanism. The incapacity of the body during fever for mechanical work indicates that all the energy or most of it passes into the heat form, represented by the lethargic condition of the body. This represents the lack of transformation from energy to mechanical activity.

The fever symptoms are, (a) an increase in body temperature. This is not only true when the skin is flushed but also when the body is chilled as manifested in tremors. The flushed skin is a good heat conductor while the skin when pallid is a bad heat conductor. According to Finlayson the sub-febrile condition varies from 37.5 to 38.5 degrees, the moderate febrile condition from 39 to 39.5 the high febrile condition from 40 to 40.5 and the hyperpyretic condition 41 and over. (b) The increased production of heat is another element in the fever. This is partly due to the increase in the circulation which passes into the heat and to the increased metabolism resulting in oxidation. (c) This increased heat production, especially the metabolism, results in the languishing effect on the body and represents the wasting of energetic activity. So much is this regarded as the great element of fever that some physiologists ascribe

the fever entirely to this hyper-metabolism. This is associated with increased O consumption and CO_2 excretion, as we said before, the increased production of urea resulting in accumulation within the system until after the critical stage is passed when it is excreted in great abundance. Accompanying these is an increase of uric acid, urobilin derived from disintegrated haemoglobin and a large increase of the potassiates. (d) The lessened heat loss varies in different fevers and the different stages of the same fever. Three stages are usually distinguished. The cold stage where there is a greatly lessened heat loss partly due to the coldness and pallor of the skin retarding the radiation of heat while the heat production continues to increase; the warm stage during which the heat given off is increased on account of the flushed condition of the skin which promotes heat radiation while there is an increased heat production; the sweating stage which represents the largest increase of heat loss because of the profuse sweating in which there is a large evaporation from the moist and flushed skin. (e) During the fevered condition there is an interference with the heat regulating mechanism. If the external temperature of a fever patient is increased there will be an increase of body temperature correspondingly greater than in the normal individual, because the heat production is greatly stimulated and the regulative mechanism is not able to control the production. Associated with the febrile condition therefore may be here stated the true osteopathic therapeutics, namely an attempt to restore the normal regulative function of the heat regulating mechanism, associated with the thermogenic and thermolytic centers in the brain and in the spinal cord and the vaso-motor center in connection with het blood supply and circulation.

Associated with febrile conditions we find other complications which may be regarded as accessory phenomona. There is usually an increase in the number and intensity of the heart beats and in respiratory activity. These represent the attempt to balance the system on a higher scale, compensating for the higher temperature by the increased heart and respiratory activity. Similarly we find decreased alimentary activity, disordered cerebral conditions, interference with secretion, a languid muscular condition, and diminished excretions. Often associated with the increased metabolic changes we find the degeneration of tissues resulting from over exertion carried beyond the stage of fatigue. In regard to the effect of fever depressants in the form of drugs we find variations, quinine and the metallic salts lessen the production, the latter especially lessening the production of CO_2. As the body temperature depends upon the heat production and the heat loss the temperature may be lowered either by diminishing the production, increasing the loss or by a combination of the two. By the application of cold water to the body heat is removed from the body so that this method has been called anti-thermic. In the use of cold water the person requires to be put into the cold bath several times to effect a lowering of temperature. Some use alcohol the effect being to promote the radiation of heat from the body; others stimulate the sweat activity so as to throw out from the body a large volume of sweat and thus carry off heat by evaporation. Some of the drugs directly affect the metabolism of the tissues thereby lessening the oxidation processes and producing a diminished heat supply, for example, quinine, the salicylates and digitalis. The osteopathic remedies however are more physiological, because to lessen the production or loss of heat simply deals with the effect and symptoms, whereas, the regulation of the heat

mechanism restores nature to its normal condition and prevents any undue interference with heat production or loss which may produce fatal results. In fever the solid food is not used up but there is a great demand for water, this demand representing the attempt of nature to wash out the waste products that accumulate in the system. When the sweat secretion becomes active it is evidence that nature is successful in this attempt to throw off the waste products.

In the case of inflammation as the name indicates there seems to be increased heat production. Experiments and clinical observations however do not justify the supposition that there is a greater heat production in the part inflamed even though the temperature is higher than a correspondent part in the body organism. The increase in temperature in inflammation is due to vascular variations resulting in dilatation and therefore an increased volume of blood in the inflamed parts. Experiments have not proved that the temperature of the inflamed parts or of the blood in that part is above the maximum of arterial blood, and in order to establish the production of heat in connection with inflammation it would require to be proved that such an increase in temperature does exist. The heat increase in inflammation is due therefore to the increase of vascular activity and partly to the increased cellular metabolism resulting in an increased oxidation in the local area giving rise to more heat.

(2) Postmortem temperature. Often there is found after death an increase in temperature. This is always found in cases of sudden and violent deaths where the individual was healthy and where death results in connection with more or less violent convulsions. This arises from the fact that heat production continues while on account of death the regulative apparatus has ceased to exercise its regulative functions resulting in diminished heat loss. At death especially where the body is vigorous there is a large capital stock in the body in the oxidation of which heat production can continue. This heat production after death results from the continued chemical action associated with the muscles and other tissues of the body, these tissues being in a semi-living condition so far as energy production is concerned, the general body vitality having been withdrawn. The body as a whole dies before its parts, the cell retaining the grasp on life more vigorously than the body. In this case there is still preserved in the tissue cells a metabolic activity and materials to furnish this activity so that until the body heat is lost so as to reduce the body temperature to a standard below this possible metabolic activity it continues to act in the production of heat. This means that after the body death the cells continue to live until exhausted when the tissue cells die. If the temperature of the body is high at the death of the body, represented by the stoppage of circulation and respiration, the heat production continues because the cooling process takes place more slowly and until this cooling takes place chemical cell activity is preserved. During the time that elapses before the rigid condition is fully developed heat continues to be produced, so that if the rigor condition comes on soon there is a greater heat production before it comes on, after which it ceases. This increased production is assisted by the lessened heat loss. On account of the stoppage of circulation and respiration heat loss is lessened so that even when heat production ceases after death as the heat loss is less marked the temperature of the body may rise on account of accumulated heat. This increase in body temperature after death is marked in cases of yellow fever, cholera and death from tetanus. Wunderlich reports that an

For converting F. into C. (mentally) subtract 32; to the result add $\frac{1}{9}$ of this remainder; divide this sum by 2, as per following formula: F. $- 32 + \frac{1}{9} \div 2 =$ C. Example: 212° F. $- 32 + 20 \div 2 = 100°$ C. For converting C. into F. multiply by 2, subtract $\frac{1}{10}$, add 32, as per following formula: C. $\times 2 - \frac{1}{10} + 32 =$ F. Example: 100° C. $\times 2 - 20 + 32 = 212°$ F.

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hour after death from tetanus he found the body temperature over 45 degrees. This is due to various processes, (a) heat production arising from the process of coagulation in connection with the myosin the coagulation process producing heat. This is found in connection with blood coagulation, where it is rapid heat production is increased. (b) Associated with death there are certain chemical changes which result in heat production. The cooling process after death is first rapid and then it becomes more slow. In connection with the rigor mortis condition heat hastens its coming on. If a muscle excised from the body of an animal like a frog is put into a saline solution at 40 degrees of temperature it at once becomes rigid; the heart will become rigid if placed in such a solution at 44 degrees and other parts of the body at varying temperatures up to 51 degrees. This heat rigidity represents a suddenly induced rigormortis because the myosin in this case while it becomes coagulated is not insoluble, as in the case of slow rigormortis.

CHAPTER X. THE PHYSIOLOGY OF MUSCLE AND NERVE.

SECTION I. Introduction.

In order that the blood may be of value to the body it must be carried to the different tissues and this is accomplished by the means of active movements of the tissues. In order that the blood may be fit for use by the tissues it must be associated with alimentary processes and to secure this there must be certain movements. These movements are associated with the muscle and nerve tissues of the body. The most of the movements of the body are carried out by means of the skeletal muscles which are closely conneted with the skeleton. When certain influences are brought to bear on these muscles they are subject to contraction so that in contracting the bones and ligaments are moved or influenced in such a way as to produce body movements. This contraction involves shortening of the muscle and is called contraction as applied to muscle which is therefore said to be contractile. We find different forms of muscle throughout the body; for example, the heart is a great muscular organ, its peculiar muscular form giving to it its contractile action as we find it associated with the heart beat. In the alimentary canal we find also special muscles the contractile actions of these muscles giving rise to the peculiar contractile peristalsis that is associated with the digestive process. Most of the body movements are thus associated with the contractile character of the muscles. It is true that we find certain movements in connection with the white corpuscles that are called amœboid movements and ciliary movements in connection with the epithelium of the respiratory passages but these amœboid and ciltiary movements are essentially the same as the muscle movements in contraction, being contractile. Hence when we analyze the conditions of muscular tissue it implies all the muscles of the body practically. All these muscular forms are under the control of the nerves because normally there is no muscular contraction that is not closely dependent upon nervous stimulation. Thus the muscles and nerves are very closely connected in these phenomena of contractility and for this reason are treated together. Microscopic examination and chemical analysis seldom give any evidence of physiological function. Hence the examination histologically or chemically

of a muscle can not give us any definite idea of its use in the body mechanism, so that we must first of all analyze the functions and then see if any explanation of this functional activity can be found in connection with the purely physical or chemical properties of the muscle.

We have seen that circulation and respiration represent two of the great functions of the body. These two functions along with digestion depend upon the activity of the muscle movements in contraction and relaxation. All the movements of the body therefore depend upon muscular action and this in turn depends on the stimulation of the nervous system in connection with nerve centers and fibres. Before we can understand how these movements are carried out and of value to the body as a whole we must find out what are the essential properties of the muscle and nerve. All muscular tissues have certain common peculiarities that may be called muscular properties which are either physical, chemical or physiological. By means of the biceps muscle the arm is bent, by means of the triceps it is extended, the eye-ball is rotated by the external rectus muscle, the ribs are raised by the intercostals—these represent different muscular actions yet the muscles engaged in them possess very similar characteristics. Hence it is said that the difference in developed special functions depends upon the anatomical relations of the muscles and the nerve connections with the brain and spinal cord. We find differences as in the cardiac muscle compared with the regular skeletal muscle but all forms of muscle whether striped or unstriped have a certain resemblance. It is this that is discussed in the general physiology of muscle tissue. When we pass from muscle to nerve we find a still further departure from the undifferentiated protoplasmic form in that it has ceased to possess contractility or at least to possess it only to a very slight extent while it retains irritability and the power of development and reproduction. The result is there is a general resemblance between muscle and nerve tissue and it is to this special resemblance that we are directed in the physiology of muscle and nerve.

One of the peculiar attributes of all protoplasm or rather bioplasm is its capacity of mobility and therefore its power to change its form. This mobility seems to be so inherent in some forms of bioplasm that it is said to be spontaneous the stimulation arising from within rather than from the outside. More generally however it is in response to an external stimulus that mobility is aroused. It is this power of motion that we find associated with muscle. Hence when the muscle is resting it is lengthened under relaxation, when it is stimulated to activity it becomes shortened and thickened and hence it is said to be contracted. It is this contractility that forms the basis of muscle function changing the form of structures, moving bones and joints. In the normal muscle we find that the structure of the striped muscle is much discussed in Histology, so much so that the history of histology gives rise to new theories of the structure and relation of the different parts. The fibre of the muscle represents the basis of the minute structure, it is surrounded by the sarcolemma a structureless membrane. The fibres vary very much in size up to 4 cm. the diameter varying from 10 to 60 micra. In the fibre we find alternating dark and light stripes having an important bearing on refraction. Some think that there is a membrane dividing the lighter part into a series of compartments, but this has been denied by Kuhne who followed the movements of a germ along the fibres unimpeded by any such septa. In regard to the sarcolemma Schaefer regards the contractile parts as delicate columns, sarcos-

tyles, separated by partitions into compartments, sarcomeres, each of the latter containing a sarcous element with a bright fluid at the ends giving rise to the light colored stripe. During the period of contraction this fluid is forced into delicate longitudinal canals which run through sarcous material. Others regard the sarcolemma as consisting of a net-work in close connection with the nuclei forming the contractile portion of the fibres, but this idea has gained no favor. It seems therefore probable that in the muscle fibre we have two different substances one part contractile and the other part non-contractile, the latter being interstitial and and forming the trophic element of the fibre and non-contractile because of its fluid or semi-fluid character. The contractile portion is found in the fibrillar part of the muscle or sarcostyle interpersed between the fibrillae being the sarcoplasm. In the case of the unstriped muscle the fibres are spindle shaped and have only a single nucleus. Of this unstriped muscle we know almost nothing because of the difficulty of experimenting with the smooth muscle in such a form as to be suitable for experiments. Hence it is the ordinary muscle that we speak of in what follows. the fibrillary threads being enveloped in the fine sarcolemma membrane. Muscle consists of a large number of these fibrillae side by side. all bound together closely and often packed in connection with the connective tissue. The unit however is the muscle fibre, a single fibre having the the power of contractility as may be seen under the microscope; however when these fibres are bundled together the muscle movements are the result of the combined contractile activity of these fibres. Hence the muscle contraction depends on the number of these unit fibres so that the strength and intensity as well as the extent of muscle contractions depends upon the requirements of the muscle at the part of the body where it is found. the difference in functional activity being based upon structural form.

It is on this basis that we have a two-fold distinction of muscles. the one form found in close connection with the bones whose function is closely connected with rapid action continued only for a short time, while the other is found in the internal organs like the intestines, the blood vessels, etc., very slow in movements and capable of great strain and long continued activity. The former represents the striated muscle and the latter unstriated having no crossings. The former are often called voluntary because dependent largely on the will stimulation, whereas. the latter are called involuntary because not dependent on the will activity. Contractility is a property of all muscle tissue and hence does not depend on structure, otherwise only some forms of muscle would possess this property.

This property of contractility is not limited to muscle. For a long time it has been recognized that mobility is an essential characteristic of minute particles of bioplasm. The amoeba represents a very minute animal found in connection with pools or in connection with some forms of plant life found growing in the water or on marshy ground. It is a jelly like structure with almost complete transparency, consisting of a large number of minute granular particles in the midst of which exists these delicate fibrillary threads with a small rounded nucleus. with a small vesicular hollow very mobile in shape and size. together with minute food balls that are passing through various changing shapes. When resting the body is flattened and irregular in form, the form being changed particularly in connection with heat. Rising from the surface are tongue-like projections or feet of varying size and shape. This

minute animal is living and capable of amoeboid mevements. When it changes its position its feet are projected forward while the body diminishes in size, the body gradually following after the projecting foot. During this locomotive action it can absorb food atoms into its own substance, excreting the waste matter also during locomotion by leaving the excretion behind. These amoeboid mevements are generally supposed to originate within the bioplasm, while mechanical, chemical or electrical shocks produce a contraction in the animal which coils itself up in a ball shape. The white corpuscles possess and manifest these same amoeboid movements. Similar movements are found in connection with the lymph and pus corpuscles. In the case of the vorticella we find an animal similar to the amoeba containing all the physiological properties necessary to life and reproduction. It is found in the shape of a bell with cilia processes at the margin and with firm and solid cuticle. When it is touched very delicately the bell shaped portion contracts, the margins being drawn down tewards the center of the interior. The contraction takes place suddenly and the following relaxation slowly. In these and similar minute organism we find the universal bioplasmic principle of excitability or the power of responding to a stimulus by manifestations of a peculiar kind that characterize physiological life. The great distinction between this contraction and muscle contraction as we find it in the higher animals is found in the fact that it takes place in any direction while the muscle contraction is uniform in direction.

A higher form of contractility is found in the cilia which are found very widely in the animal kindgom. In many of the bacterial forms we find the ciliated contractions. In the human subject we find the ciliated epithelium in several layers the outermost one being pear-shaped the wider end on the surface, while it is covered over with minute and delicate cilia. These cilia are found in the respiratory passages, in the midear, in the Eustachian tubes and in the fallopian tubes and in the central cavity of the brain and spinal cord. When placed under the microscope the motion is so rapid that it is difficult to distinguish the movements, for example, in connection with a frog's palate; there is found to be a stream of liquid going in a constantly uniform direction along the edges of the cilia. As the motion is lessened when the O becomes scarce the cilia are found to bend in one direction following the fluid stream, the relaxation coming on slower. The movement is found to be undulatory moving along the cilia from row to row in connection with the respiratory tract, these cilia movements upward and downward assist in the throwing out of foreign particles and other pathological elements. This represents the principle of contractility that is associated with all living bioplasm.

Another of the properties very closely connected with this as found in living matter is irritability. It is the property in virtue of which living matter undergoes certain changes physical, chemical or electrical under the influence of certain stimuli which act as irritants. Muscle is very irritable and readily responds to stimulation in connection with mechanical, electrical or chemical changes. The skeletal muscles do not move automatically and hence do not manifest spontaneous irritability. Such automatic activity depending upon internally originated impulses is found in connection with the infusoria and it is claimed that the cardiac contractions in connection with heart rhythm are of the same nature. Closely allied to these two principles is the principle of conductivity found in connection with bioplasm. Conductivity represents the principle in

virtue of which the substance when irritated transmits the commotion along the irritable bioplasm. When an external stimulus irritates a small part of the substance the irritability is transmitted along the substance as an impulse so that the irritation passes from section to section along the bioplasm.

Irritability and conductivity are not confined to muscular tissue they are found in a higher degree in nerve tissue, although nerve tissue does not have the power of mobility or contractility. In the nervous system we find the nerve fibres and cells, the latter in the brain, spinal cord and in the spinal and outer ganglia along the path of the nerve fibres. In the nerve fibres the axis cylinder represents the active part of the nerve this axis cylinder representing the developed out process of a cell which when it passes beyond the central nervous system is enveloped in a neurilemma. Among the nerve fibres we find some medullated and some non-medullated, the former having a medial medullary substance between the axis cylinder and the neurilemma, while the latter have not this medullary sheath. When the nerve fibre is irritated the fibre possesses the power of transmitting the nerve commotion along its length, sufficiently strong to excite the cell to activity. Thus the nerve fibres represent the paths between the nerve cells in the central system and the neuro-muscular end organs as well as the muscular and glandular cells. The nerve fibres are centrifugal and centripetal as they carry impulses outward or inward in connection with the central system; those arousing muscular activity being called motor; those found in connection with the blood vessel walls vaso-motor; those terminating in the glandular cells secretory and those terminating in the sensorium in the brain sensory nerves. The principle of conductivity is the same in all the different fibres the effect depending on the originating organ and the terminating organ. Nerve fibres are bound up in the trunks, the centrifugal and centripetal running side by side in the same trunk, the fibres of different kinds being bound together by connective tissue. In connection with the neural substance there is no contractility but the protoplasmic substance possesses most of the properties associated with muscular protoplasm. All cells in connection with bioplasmic matter have originated from two primative cell forms. When the fecundated ovum divides it forms two cells, these two original cells dividing, this division going on side by side with an arrangement of cell in structural forms developing into the organism of the embryo. While the dividing process goes on the enlarging process goes on also, each cell taking on new matter and thus enlarging the protoplasm. While this nutritive process goes on the cells assume their structural forms in connection with cell differentiation. In this differentation process we find that certain characteristic features of one kind of cell become specialized while in the other kind of cell a similar specialization takes place along a different line. The original cells do not possess all the properties of developed cells but they do possess certain properties that all cells have in common, namely that of taking in and using materials in the process of upbuilding and enlargement, the power of liberating energy suitable to the cell life in connection with the chemically changed food elements and and also the power of eliminating unsuitable and waste elements together with the power of reproduction. It is claimed by some that the original ovum has the properties of contractility, irritability and conductivity; in some cases the contact of the spermatozoon and the ovum resulting in the fertilized ovum, the oval external protoplasm forming an external

membrane to prevent the contact of other spermatozoal forms. Thus in the fertilized ovum we find irritability and contractility these being the important principles at the basis of the processes of fecundation and differentiation, these properties becoming the special property of all the divided cells until specialization of function becomes more complete, when in muscle the principle of contractility becomes a permanent characteristic and in nerve fibre the principle of conductivity. Thus we find in ascending the scale of animal life from the lowest amoebic form that the properties of bioplasm are uniformly developed becoming more differentiated as we come to forms of life where rapid mobility is required the several kinds of tissue being adapted to these special forms of motion. As the contraction becomes more rapid the tissue differs more from the original protoplasmic cell and as the contraction becomes slower it adheres more closely to the original protoplasmic cell.

In the minute capillary walls the muscular contraction is very slow and the relaxation is quite primitive giving tone to the capillaries, whereas in the intestinal movements we find rapidity and also a delicate and elongated muscular cel. The cardiac movement is quick and powerful but not quick when compared with the sudden action of a skeletal muscle, so that we find both the slow and quick movement associated with the complex cardiac muscle. In regard to the connection of muscle and nerve the nerves branching among the fasciculi of a muscle divide and subdivide in the formation of a large number of branches forming the intermuscular nerve plexus. Arising out of these ramifications we find very delicate branches each consisting of a medullated fiber which ends in the muscle fiber. When a nerve enters a muscle there are not corresponding fibers in the nerve for every muscle fibre but when the nerve enters the fibre of muscle the axis cylinder is divided into as many fibres as correspond with the muscle fibres. As the nerve enters the muscle fibre it loses the white substance of Schwann, the axis cylinder passes through the sarcolemma and ends in the muscle fibre in an end plate. We find great variations in these end plates, some of them consisting of very delicate fibres in which the axis cylinder is split up forming a meshwork by anastomosis, while others assume the form of irregularly shaged granular discs with a large number of vesicular nuclei. Here there is established an inseparable relation between the nerve and muscle tissues, the one blending into the other. The axis cylinder is spread out into a net work of minute processes, the central portion forming a kind of capillary part around which the minute processes radiate, these find fibrils ending in the muscle fibres.

Before passing to the discussion of the main subject we must speak of the chemical and physical properties of the muscle fibres. (1) The chemical properties of muscle. Muscle fibres consists of the muscle plasma which can be pressed out of the muscle in a recently killed animal, representing a neutral or very slightly alkaline fluid of gelatinous character; and an insoluble element consisting chiefly of sarcolemma, nuclei, fat and the more solid elements of blood vessels, nerves, lymphatics, together with muscle tissue. Acetic acid does not affect the sarcolemma but if it is heated along with acids or alkalies it will dissolve slowly. It is claimed on account of this to be analogous to elastin. In the muscle there is a doubly refractive element of contractile discs in the case of striated muscle whose composition is unknown. If the muscle is deprived of blood and then subjected to pressure at a low temperature of 8 to 10 de-

grees C the muscle plasma may be obtained. It is derived from the isotropous part of the fibre. As a fluid it is colorless or slightly yellowized, alkaline in reaction and containing several albuminous substances. When pressed out it very rapidly coagulates dividing into two parts— the myosin and myosin serum. Its coagulation is retarded by keeping it cold and accelerated by heat, ammonia, weak acids and distilled water. The myosin is albuminous in composition soluble in five percent solution of sodium chloride or very weak HCl acid. By the use of the latter in a very weak solution .1 percent it is transformed to syntonin, this substance being insoluble in NaCl solutions and in sulphate of magnesium solutions.

The muscle serum contains when exuded from the myosin, (1) water about ~~70~~ or 80 percent. (2) Albuminates such as potassic albuminates precipitated by heat over 20 degrees C. It is not myosin as it is insolable in NaCl solutions. If the serum is made acid and heated to 75 degrees C it will yield serum albumin and also an alkaline potassic albuminate. (3) Ferments are found in connection with the serum including the muscle ferment, pepsin and ptyalin. (4) Pigment, the muscle haematin almost identical with haemoglobin. (5) Various nitrogenous extractives including lecithin, kreatin, xanthin, taurin, urea and uric acid. If muscle fibre is placed in cold water the muscle gives up some of its elements that redden the water. By boiling this reddened water the proteids are coagulated and by filtering the liquid part there is found a liquid having in solution the nitrogenous and non-nitrogenous matters. When this liquid extract is free from proteids and then thickened by evaporation it is called the extract of meat. (6) Non-nitrogenous matters including fats, sarcolactic and ethylene-lactic acid, muscle sugar, glycogen and dextrin. Glycogen is found in muscle varying from .5 to one percent. The volatile acids have also been found, such as formic acid and in dead muscle the sarcolactic acid is always found. (7) Salts chiefly the phosphates of the alkalies and the alkaline earths, potassic chloride and a small quantity of NaCl. (8) Gases. In a hundred parts of muscle CO_2 has been found to the extent of 14.4, N 4.9, O .09 representing in all 19.39. It is claimed that a large proportion of the CO_2 found results from death arising in connection with muscle decomposition. In human muscle Bibra gives the following quantitative analysis 74.45 percent of water, 25.53 of solids including 1.93 of albumin, 2.07 gelatin, 3.71 alcoholic extract, 2.3 of fat and 15.54 of vessels. In a resting condition the living muscle is alkaline on account of the presence of the potassium phosphates. Passing from rest to activity it becomes acid chiefly on account of the formation of the lactic acid and according to some due to the formation of the acid potassic phosphate. Our knowledge of the chemistry of muscle is chiefly derived from the investigations of Kuhne on the muscles of frogs. Halliburton has made many recent additions to our knowledge in regard to the muscles of the warm blooded animals by experiments in connection with horse and rabbit muscles. He obtained plasma from the muscle of the rabbit by washing out the blood from the vessels by a .6 percent solution of NaCl at 5 degrees C. and placing the muscle in a freezing mixture of ice and salt at a temperature of 12 degrees below zero C and then subjecting muscle to pressure. As a result he found a yellow viscous fluid slightly alkaline in reaction that formed into a solid jelly in from one to two hours at a temperatnre of 40 degrees C. Halliburton found that coagulation takes place in from 20 to 30 minutes while the alkaline reaction gives place to an acid reaction. He found that a solution of neutral salts prevented the coagulation of the

plasma and that the dilution of salted muscle plasma caused or induced coagulation. The plasma is not separated into the coagulum and salted serum at zero C but it occturs most freely at body temperature and if a ferment prepared for muscle as Schmidt prepared his blood ferment is added the coagulation is accelerated.

The proteids of the muscle plasma are five in number according to Halliburton. (1) Paramyosinogen which is coagulated by heat at 47 degrees C; (2) Myosinogen found to coagulate at 56 degrees C; (3) Myoglobulin which differs from serum globulin in the temperature of coagulation, coagulating at 63 degrees C; (4) Albumin the same as serum albumin which coagulates at 73 degrees C; (5)Myoalbumose almost identical with the muscle ferment. The first of these forms the myosin coagulum and the other three are found in the muscle serum. The first three belong to the globulin family. When the muscle becomes acid by the formation of lactic acid as in cadaveric acidity the pepsin it contains begins to act and at the temperature of 35 to 40 degrees albumoses and peptones arise. Halliburton supposed that the passing away of the rigor mortis which arises from the conversion of myosin into myosinogen again may represent the initial stage in this digestive process. In regard to the muscle ferment which has been much discussed Halliburton concludes (a) That proteids are coagulated by preserving muscle in alcohol for several months. From this alcohol precipitate distilled water will extract an albumose proteid. (b) This albumose presents the characteristics of a ferment since it will coagulate muscle plasma. (c) This muscle ferment does not accelerate the coagulation of blood plasma neither does the fibrin ferment accelerate the coagulation of muscle plasma so that these do not represent the same ferment. (d) That fluid pressed out from the muscle accelerates very decidedly coagulation in the salted muscle plasma. This arises from the presence not of fibrin but myosinogen which coagulates thermally at75 to 80 degrees C. (e) The fibrin ferment losses its coagulative properties from 75 to 80 degrees C whereas the myosin ferment does not lose its fermentive capacity till 100 degrees C.

(2) The physical properties of muscle. Associated with the muscle are certain physical properties which must be considered before coming to the consideration of the muscular phenomena. (a) Consistence or firmness. In relaxation a muscle is soft, in a contracted condition it is hard and firm. Inside the sarcolemma we find a soft substance which after the rigor mortis condition comes on becomes hard and solid. In the living condition of the muscle this is in a semi-fluid state. It is not fluid so that it will flow like liquid nor is it solid so that it can be distinctly separated in all its parts. By the use of a compressor this fluid may be expressed from the sarcolemma. In the case of the living muscle there are found undulatory movements of this fluid. Kuhne watched the movements of a parasite through this semi-fluid matter in the muscle fibre, the movements being free as if floating in a viscous substance. By passing a current af electricity from end to end of the fibre it is found that there are flowing currents passing through the muscle so that the internal structure of the muscle fibre must be semi-fluid. (b) Cohesion. Cohesion represents a physical force that unites two molecules of the same nature, for example, two molecules of water. Cohesion is strongest in solids, less strong in liquids. The cohesive intensity decreases as the temperature increases on account of the increase by the heat of a repulsive force

or resistance. In muscle tissue the cohesion is less strong than in connective tissue. Weber estimates that a square centimeter of muscle from a frog will bear one kilogram in weight without any interference with cohesion. When muscle irritability is lost cohesion is diminished. In the living muscle therefore cohesion represents the uniting force in virtue of which form is preserved against heat from liquefaction and dissolution. (c) Extensibility and elasticity. These represent the physical properties in virtue of which a substance or body tends to resume its original form when after having been subjected to pressure or torsion the force which altered its form is withdrawn. Its extensibility refers to the capacity to yield under pressure to elongation, and elasticity is the property of resuming its original position. During rest the living muscle has only a small elasticity although it is perfect. Liquids have elasticity in volume, solids both in volume and form. When subjected to pressure it will elongate and return on removal of pressure to its former length. Muscle elongations are not in proportion to the weights that produce stretching, the amount of stretching diminishing with the increase of the weight. For this reason the curve of muscular extension is a hyperbola and not a straight line. In order to get the curve we mark out in abscissae the unit weights drawing the ordinates to form the amount of extensibility. If these points are joined a curve will be found of the nature of a hyperbola. This means that the elasticity of the muscle increases with the stretching of the muscle. There is however a limit to this extensibility, because as Marey points out, if the gastrocnemius muscle of a frog is stretched with a weight of 100 grams it will not return to its original form. The extensibility of a body is estimated by the ratio of length increase resulting from the unit stretching force per unit of area in the cross section to the original length of the body. We find that living muscle is very extensible, the extensibility lessening gradually as the lengthening, so that to increase the stretching force lessens the extension. This large extensibility and elasticity of muscle are very important in connection with the blood vessel changes and in diminishing the shock to the heart and the vascular system. Weber points out that when contracted a muscle has a lessened elasticity. He tetanized the hypoglossal muscle of a frog fixed at one end and weighted at the other. He contrasted the elongation during contraction and that during rest in the muscle. In the case of the contracted muscle he found a greater elongation than with the resting muscle using the same force. He saw in addition that if a muscle resting is heavily weighted and then irritated it becomes longer and not shorter, in other words the contraction does not take place, the lessening of the elasticity being more than sufficient to counterbalance this shortening in contraction. Wundt and Volkmann contradict these results claiming that the lessening of muscular elasticity does not depend upon activity as distinguished from rest but only upon the muscle shortening, hence he concludes that muscle elasticity is practically the same in rest and during activity. Donders found in connection with the flexor muscle of the human forearm that when it has been stretched by a heavy weight and when the weight is taken away the return to the normal length does not take place for a considridable time, sometimes for days or weeks. This has been called the elastic after effect. Muscle elongation therefore depends upon the weight in normal cases less than fatigue; the elastic degree or the amount of elasticity is about the same for different degrees of contraction within

normal limits; beyond these limits amounting to fatigue or over exertion the elasticity is diminished or destroyed.

Marey concludes that elasticity assists in the economy of muscular exertion because the weak muscle elasticity does not strongly resist great force so that when the force is withdrawn the muscle returns to its normal without any loss of force. During life the muscles are normally in an extensible condition between the attachments of bone, tendon and ligament so that they are always in a state of tension or tonicity. This depends on the contraction arising from opposing muscles or even from the skeletal attachments. When a muscle is cut across or even its attachment is severed it contracts. The normal tone favors the production of muscular energy, because the muscle tone is favorable to activity so that as soon as contraction sets in mechanical exertion begins. It is claimed that this muscle tone depends on the nervous system. By dividing the spinal cord below the medulla and then dividing the nerves to the leg on one side, the muscles in the leg on the same side become soft and loose and the leg is elongated beyond its normal length. This indicates that the spinal cord furnishes the innervation to the muscles. Heidenhain claims however that in the case of a muscle when the nerve connection is cut off it does not become longer. There is here however mechanical injury so that probably the innervation and blood circulation form necessary elements in the muscular tone of all the muscles. Evidently then the muscle is both extensible and elastic, being capable of yielding under the influence of weight and also of returning to its original dimensions when the pressure is taken away. Extensibility and elasticity are very valuable in the human body on account of their value in modifying the effect of rapid muscle contractions causing the contraction to take place more slowly and so preventing a rupture in the tissue as well as preventing sudden changes.

(3) Histological properties. We have seen that there are two classes of muscle, the skeletal and the muscles found in connection with the blood vessel walls and the visceral organs. Between these two we find the cardiac muscle that is intermediate between the two. The striated muscle is sometimes distinguished into pale and red, the former being more perfectly organized, striation being more complete and the nuclei less numerous. The structure of the striped muscle is the subject of much controversy. All agree that the sarcolemma contains contractile and non-contractile fluid elements. In connection with the muscle it is found by examination under the microscope that when contraction takes place resulting in the shortening and thickening of the muscle fibre the cross striae approximate more closely to each other, the dark and broad stripe of the muscle in rest changing to the narrow light stripe of the active muscle. The contractile substance is anisotropous while the non-contractile is isotropous, the former causing a double refraction of light and the latter a single refraction. By examining the muscle fibre in connection with the polarization microscope the double refraction appears to be light in a dark field. When the fibre contracts the contractile portion of the fibre is narrower and broader. Bruck concludes that the contractile elements are not simple but consist of a large number of minute doubly refractive elements found arranged in series, these changing their position and form during contraction. These minute elements he called disdiaclasts. Waller says that the dark stripe of an uncontracted muscle fibre and the light stripe of a contracted fibre are both doubly refracting,

becoming a light band in a dark field. This however is true only of muscle when dead and partially contracted in connection with osmic acid. The interstitial elements are loose the sarcolemma being elastic giving to the muscle its retractile power after being extended.

SECTION II. Apparati and Modes of Exciting Muscle and Nerve.

In the study of muscle and nerve phenomena stimulation requires to be applied to the muscle or nerve. The most suitable and effective stimulus is that of electricity. Electricity may be applied in different ways, hence we require to discuss the modes of application before making the practical application in connection with the muscle and nerve. An electrified body charged with electricity is said to possess a certain electrical potential. If we immerse a plate of zinc or copper in a sulphuric acid solution the metal and the liquid have different electrical potentials. If zinc and copper are both immersed there is a difference in potential between the zinc and copper. If the two plates are united externally by a copper wire there will be a difference in potential between the zinc and liquid, the liquid and the copper, the copper and zinc. When we sum these differences we find that they are not zero and hence as the electric current flows from a higher to a lower potential an electric current flows from the zinc to the copper through the liquid and from the copper to the zinc on the external wire. As the current passes from the zinc to the copper through the liquid decomposition takes place in the liquid so that the current is kept flowing, the chemical action producing the necessary energy to keep up the flow. Chemical action produces sulphate of zinc in connection with the zinc and liberates H from the sulphuric acid the H liberation taking place at the copper end. This represents an element, the metals being plates, the liquid electrolyte and the positive and the negative poles being at the copper and zinc respectively in connection with which we find the electrodes. The sum of the differences of potential represents the cell potential or when the circuit is completed by closing the external wire it is called the electromotive force or the force which produces the current flow. It represents the difference of potential in the case of the plates when no current is flowing. When, however, the circuit is closed and the current is flowing there is an electrical resistance in connection with the liquid and the solid elements. The wire opposes the electric current and this is called electrical resistance. Hence to overcome this resistance a greater electromotive force is necessary the current being stronger in the thick than in the thin wire. Hence Ohm's law represents the relation of current, electromotive force and resistance, $C = \frac{E}{R}$. The resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional area. When these elements are formed singly and then combined together we have a battery. Serial union of cells takes place when the positive of one cell is united with the negative of the 2nd cell and so on. This represents tension. Superficial union takes place when all the positive and all the negative are united together. The electromotive force depends on the chemical changes and also on the temperature of the changes so that in a battery there is an internal as well as an external resistance, so that the increase of resistance weakens the force of the current. Sometimes the cell becomes ploralized, for example by the accumulation of H at the pos-

itive pole. This increases the resistance and produces a new force that also lessens the electromotive force of the current. Where a battery is formed it is better to arrange the cells in groups, two of ten cells or three of 15 cells so that the resulting battery consists of two or three batteries, joined together in groups of ten or 15 cells parallel to each other, the terminal zinc and copper in the one being joined to the terminal zinc and copper respectively in the other.

The system of measurements used in connection with these experiments is the metrical system. The electro-magnetic unites are used in connection with the forces exerted between two poles. The unit quantity of magnetism is the quantity of magnetism which when at a distance of one cm. from an equal quantity of magnetism will repel it with a dyne force, which is the force acting on a gram for a second producing a velocity of one cm. per second. The unit magnetic field represents the field resulting from a unit quantity of magnetism at a distance of one cm. A unit current of electricity represents such a current as when it flows around a circuit of one cm. radius produces a magnetic field of as many units in intensity as there are cms. in the length of the circumference of the circuit. The unit quantity of electricity is the amount conveyed by the unit current in a second of time. The unit e. m. f. is that produced in connection with a closed circuit when one cm. of the conductor is held at right angles to the direction of the magnetic force in the magnetic field and moved uniformly at a velocity of one cm. per second at right angles to its own length and the direction of the magnetic force. Unit resistence represents the resistance which when acted on by a unit e. m. f. admits of the passage of a unit current. The unit of current is the ampere, the unit of e. m. f. the volt, the unit of resistance the ohm. The ampere represents approximately the current that passes in a Daniel cell through an ohm, the volt approximately represents the e. m. f. of a Daniel cell and the ohm the resistance of a column of mercury one mm. sq. and 1,050 mm. long at O degrees C. Among the voltaic elements the Daniel cell is the most common. It consists of a glass jar containing a solution of sulphuric acid diluted in the proportion of one to seven; within this is placed a cylinder of zinc inside of which is a porous earthenware jar containing a copper roll immersed in a solution of copper sulphate. By the action of the sulphuric acid sulphate of zinc is formed and H is liberated. The H passes through the porous vessel and reduces part of the sulphate of copper depositing copper on the copper roll, the sulphuric acid passing to the acid solution in the outer jar compensating for the loss of acid in connection with the formation of sulphate of zinc. In this way a continuous current is kept up so long as the crystals of copper sulphate are kept in the interior compartment and while the zinc lasts. The e. m. f. of this element is 1.072 volts The positive electrode is in connection with the copper and the negative in connection with the zinc. The Bunsen element substitutes a carbon block for the copper and it is placed in a strong nitric acid solution. The positive electrode is in connection with the carbon and the negative in connection with zinc. The nitric acid absorbs the H liberated in connection with the sulphuric acid and zinc thus preventing polarization. The e. m. f. is 1.9 volts. In the Grove's element platinum is substituted for C, the e. m. f. being 1.96 volts. In connection with a dynamo all of these elements may be dispensed with by the use of an accumulator for storage purposes.

In connection with the principle of induction we find the important

principle discovered by Faraday that when a current passes along a closed circuit a current may pass to a contiguous coil through induction. In the induction coil we have a primary and a secondary current, the primary current representing the inducing current and the secondary the induced current. The law of Lenz in regard to the currents is that the direction of the induced current is always in a direction tending to oppose the change in the primary current. The primary current is formed by a considerable length of wire wound around a bobbin, the wire being insulated by the use of silk or cotton and the turns being varnished. The two ends of the wire are united by brass screws to which the wires from the cell can be attached; when attached the current will pass around the coil. The secondary coil is similarly formed out of thinner wire and the wire must be very much longer as the induced current intensity depends on the number of turns in the coil and the fineness of the wire. The ends of the wire are connected to a brass screw to which the wires can be attached so as to lead off the induced currents, for example to a galvanometer. The coils are so arranged that the primary can be slipped out or in to the interior of the hollow secondary coil. This is called the induction coil. The secondary current induced in connection with the secondary coil when opened is in the same direction as the primary, while when closed it is in the opposite direction, so that at each opening and closing of the primary current the secondary current is reversed, the opening shock being stronger than the closing one. In the primary coil there are usually 432 coils with a resistance of 1.27 ohms and the secondary 14,680 with a resistance of 1,362 ohms at 16 degrees C. When the secondary coil is placed on a ratory disc so that it can be placed with its axis at an angle in connection with the primary coil the strength of the secondary current can be modified on the basis of deviation which is marked on the graduated arc.

In order to open and close a current keys are used. A key consists of a rectangular wooden frame for screwing to the table on the upper surface of which is a vulcanite block with two rectangular brass bars united by means of a handle. When this handle is horizontal the key is closed, when the arm is raised the key is oepn. The wires are attached to the rectangular bars so that if the positive and negative electrodes are concected with the two bars when the key is closed the current will be placed in a short circuit and when the key is open the current will pass on uninterrupted. For the reversing of a current the commutator is commonly used. It is a wooden disc with six small depressions at regular intervals to each of which is attached a binding screw. In the two central holes two wires are attached at the outer ends to the ends of the binding screws so that these wires can move freely from side to side. These wires are connected above to a piece of vulcanite the interior ends not meeting so that a bridge is formed. If a current enters the end of the bridge by the positive side it could not pass to the bindlng screw having a negative attachment on the opposite side. Two curved wires are attached to the ends of the bridge so as to fit into the depressions on either side of the bridge, so that as the bridge is moved the ends of these cross wires can dip into opposite depressions. These cross wires are used to reverse the direction of the current. In connection with the muscle and nerve, various apparati are made use of to stretch the muscle and nerve and provide for the stimulation of the muscle and nerve as in the muscle telegraph.

Muscular and nervous changes are too rapid to be followed by the eye, for example, the heart motion when the heart is exposed in the case of a living frog can not be studied with the eye nor can the movements be followed out with sufficient accuracy to permit of being measured, so that appliances have been invented in the form of the drum or revolving kymograph which permit of the recording of these movements and variations on a blackened surface. This is the graphic method of the registration of movements and variations recorded on a blackened surface. As many of the phenomena associated with muscular and nervous actions are of such short duration it is impossible to observe them with the unaided vision, hence minute apparati have been invented for the purpose of measuring short intervals of time. Among these we find the recording cylinder which revolves at a uniform rate by clock-work. If the cylinder surface is divided into 60 lines, parallel with the axis and at equal distances from each other, if the cylinder makes one revolution in one second the distance between two lines will represent one-sixtieth part of a second and whatever is recorded on the cylinder between those two must have taken one second. The cylinder has been graduated to measure the one-thousandth part of a second, the difficulty of causing the cylinder to revolve uniformly being got over by the use of regulators. In order to utilize the revolving cylinder a chronograph is necessary. Young invented this method of marking on a revolving cylinder the vibrations of a rod carrying a minute marker. If these vibrations are uniform the undulations marked on the cylinder will correspond with regular intervals of time. The vibrations of a tuning fork may be marked out in this way by attaching to one of the limbs of the fork a marker so that when the surface that receives the tracing revolves with suffiicient rapidity periods of one five-hundredth part of a second may be easily repesentde. In order to record the vibrations accurately a marker is devised vibrating in harmony with a tuning fork which is kept in activity by electric currents so that the apparatus consists of a battery, an interrupting tuning fork and the chronograph. The tuning fork interrupts the current from the battery automatically. As the metal of the electro-magnet between the tuning fork limbs becomes magnetized the limbs come closer together and a small piece of platinum wire attached to one of them is removed from contact with a platinum surface, thus breaking the circuit. When the circuit is broken the electrical magnet ceases to act, the tuning fork limbs separating from each other, bringing the platinum wire into contact with the platinum surface and thus closing the circuit again. In this way the chronograph vibrates in harmony with the tuning fork giving accurately the results and being capable of very easy adjustment.

Sometimes it is important to find out the period of the beginning or ending of a phenomenon, this is done by the use of an electro-magnetic apparatus. It consists of two electro-magnetic bobbins which, as soon as the current passes, attract a plate of steel placed over them and pull down the recording marker and thus form a low horizontal line. By interrupting the current the lever is elevated by a spiral spring which marks an upper horizontal line until the closing of the current. The opening or closing of the current takes place either by the use of a metronome or a tuning fork or by the seconds pendulum of a clock. By this arrangement the time of the beginning and ending of any phenomena may be registered. By attaching a lever to the moving structure as close to the fulcrum as possible and placing the other end of the lever in contact with the reg-

istering surface movements may be recorded. In recording muscular movements the myograph is a convenient instrument. The best simple form is the spring myograph of DuBois Raymond. It consists of a rectangular plate of glass moving in a horizontal direction along through delicate steel wires. Its horizontal movement is accomplished by a recoiling spring which is subject to check by an apparatus at the other end. When applied in this way the muscular contraction will give a curve. If the rod that carries the steel spring is removed the glass plate may be moved in front of the marker by a long screw attachment to the plate by means of a handle a little below. Marey makes use of the double myograph which differs from the other in having a second lever so that, for example, the two gastrocnemei muscles of a frog may be attached each to a lever. The two levers are placed over one another so that two tracings are given. In this way it is possible to study the contractions that are given by two muscles, the one in a normal condition the other in an abnormal condition. Marey's method is of advantage because it registers the tracing of muscle contraction so as to indicate accurately the different periods and changes in the movements.

One of the main difficulties in recording animal movements it that of attaching immediately to the body a marker that may be used for inscribing the different phases of the movements and variations on a recording surface. In order to get over this difficulty instruments have been invented for the transmission of movements to a distance from the body before being recorded. These instruments are called Marey's tambours or drums which are united by tubes that contain air. This tambour consists of a hollow metal case, the upper surface of which is covered by a delicate membrane which supports the writing lever. Two tambours each with a short metallic tube communicating with the interior may be united together by connecting them with an india rubber tube from the one metal tube to the other. When the membrane in the first tambour is thrown down part of the air in it is driven out passing through the india rubber tube into the second tambour the membrane of which is raised, the motion being passed to the lever and recorded on the kymograph. The first tambour is called the receiving and the second the recording tambour. The movements of the recording tambour are in opposite directions as the movement of the one is drawn down the other is forced up. If it is desired to get the lever movements in the same direction one of the tambours requires to be reversed. The special value of this mode of transmitting movements is that it is possible to record on the same surface a number of movements taking place in different ways so that we can have the means of comparing the resulting curves side by side. Marey has used this method of transmission in studying the phenomena of muscular contraction. By making the contracting muscle act on a tambour this movement may be carried to a distance to another tambour which will record it on the drum. By the use of these tambours muscle may be subjected to different temperatures or to the influence of various gases without in any way interfering with the recording of the movements. These tambours are very sensitive, for example, they can record with accuracy the delicate vibrations of a tuning fork. It is for this reason that the tambour is so commonly used in physiological experiments because of the accuracy in transmitting and recording movements and variations.

In order to the exact and careful study of electric excitability the unpol-

arizable electrodes must be used. In their preparation an amalgamated zinc rod is dipped into a sulphate of zinc solution diluted communicating with a clay plug made into a paste with a solution of NaCl. All of these are dipped into a glass holder. Its use is of value because it is not polarizable in connection with weak currents and does not itself produce any e. m. f., having high resistance and being capable of application in connection with the living body tissue without any injury. The D'Arsonal unpolarizable electrode consists of a silver rod coated with fused silver chloride dipped into a glass dish containing a saline solution. In connection with the application of electric stimulation it is important to have the stimuli regulated when used in a series of stimuli. This is done in connection with the rheotome by means of which a series of stimuli can be brought in and led away to a galvanometer. This is accomplished by a revolving bar with two contacts one in the primary circuit and the other in the galvanometer circuit. If the bar revolves once in a second and finishes the galvanometer circuit in connection with a pair of metals one-hundredth part of the circuit, the circuit is closed each second for one-hundredth of a second. The circle that carries the primary contact revolves around the circuit carrying the galvanometer contact, the two can be set so as to be simultaneous or so as to place the galvanometer contact one-hundredth or two-hundredth part of a second later than the other or the revolutions can be regulated at any rate.

MODE OF EXCITATION.—Stimulation may be imparted to muscle in addition to the normal stimulation of muscle by nerve—CHEMICALLY. Many chemical agents produce contraction by influencing the chemical muscle composition or that of the nerve which supplies it. Among these we find the stable alkalies, mineral acids, acetic and lactic acid, alcohol, ether, the neutral alkaline salts such as NaCl and Sulphates and carbonates of the alkalies, metallic salts such as iron, lead, zinc, copper and silver salts and some concentrated solutions of urea, glycerine, and sugar. Weak solutions of these excite the contraction of the muscle, stronger solutions being required in the case of nerve excitation. A weak bile solution also stimulates muscle contraction, HCl vapor produces single contractions while chlorine gas tetanizes. Bisulphide of carbon vapor stimulates the muscles through the nerves, dilute solutions of caustic soda or potassium stimulate the nerve and then destroy it. Rhythmic contractile movements are produced in the muscles by the use of Biedermann's solution consisting of five grams of NaCl, 2 grams of alkaline phosphate of soda and one-half gram of carbonate of soda in one and ¾ pints of water. If a frog is given curari and then the sartorius muscle is taken and plunged into this solution the muscle shows rhythmic contractions almost identical with the cardiac pulsations. This has suggested a theory in regard to rhythmic action that the rhythm of the pulsating organs may be due to certain chemical substances freely circulating through these organs. It is claimed that the chemicals stimulate the muscle and the nerve extracting water out of them as the same contractions may be found in connecttion with the exposure of a muscle or nerve to the air by which it becomes dried. When pure water is injected into the blood circulation of a muscle the individual fibres are stimulated to activity producing fibrillary contractions, exciting the blood directly and through the blood exciting the muscle to contraction. All chemical substances that change the chemical composition of muscle with sufficient rapidity act as stimuli. Curari injected into a frog produces paralysis of the intermuscular ends of the

motor fibres the muscles continuing excitable. (2) THERMAL STIMULATION. The sudden change of temperature in a muscle either higher or lower produces muscle contraction, if the temperature is gradually raised to 45 degrees C the contractions become stronger. Tetanus will be produced if the temperature is raised to 60 degrees, over this limit coagulation begins and results in the hardening of the muscle. If a muscle of a frog is quickly heated to 28 degrees contraction takes place gradually and increases slowly; by raising the temperature to 30 degrees the contraction is more marked and by raising the temperature to 45 it reaches its maximum. This rise in temperature produces heat rigor. In the case of a warm blooded animal if the smooth muscles are warm they contract while in the cold blooded they become extended. By cooling the muscle of a frog to zero C the muscle becomes very irritable, especially to mechanical stimulation. Bernard found that where artificial cooling takes place after death the muscle continues irritable. (3) MECHANICAL STIMULATION. The effect of mechanical stimulation depends on the nature and intensity of the stimulus and also the manner of application as well as the suddenness of application. If compression is applied slowly to a muscle no contraction generally follows, whereas if the pressure is applied suddenly and rapidly contraction usually follows. If a muscle is struck across the fibres perpendicular to the direction of the fibres with a blunt instrument the whole muscle gives a single contraction and then relaxes, but the part of the muscle that receives the blow remains contracted for a time. This phenomenon is called by Schiff idio-muscular contraction. It will often follow such a stimulus as that produced by a blunt instrument when no other stimuli cause contractions. This results in a local contraction which may take the form of a weal or welt. The contraction extends over the entire muscle at first and when the contraction disappears there is left at the point of concussion a swelling. The moderate tension of a muscle produces increased irritability.

(4) ELECTRICAL STIMULATION. Electrical stimuli produce the greatest effect when the current moves in the same direction as the muscle fibres. A single electrical shock if sufficiently strong will produce a single muscle contraction for a number of shocks in succession at brief intervals will produce muscle spasms or tetanus. If the current of a voltaic battery is sent through a muscle there is no apparent contraction in the muscle except when the current is opened and closed or when a sudden increase or decrease of the current takes place. By placing the muscle in the electric circuit and opening and closing the current a tracing is found which is different from that of a nerve, the relaxation period being very much longer because relaxation takes place very slowly. During the passage of a current through a muscle electrolytic changes take place, heat being produced on account of the resistance which the current meets with in passing through the muscle. By curarizing a muscle and then placing it in an electric circuit when the current is opened there is started a wave of contraction from the positive pole that sweeps over the muscle and when the current is closed another wave of contraction starts at the negative pole. If the nerves are paralyzed the muscle gives a very much more free response to the electric current when it is opened and closed, if the voltaic current is used, muscular protoplasm being more free to respond to the shocks produced in opening and closing a current, the nerve and neuro-muscular terminals not being susceptible to such shocks.

In connection with muscle excitation heat production in muscle is an important point. By the use of the thermo-electric needles passed through the muscle in such a way that the iron and copper unite in the muscle and the iron and copper unite outside the muscle, the contiguous ends of the needle are attached to wires in connection with the galvanometer. For more delicate experiments the thermo-electric pile is used in which we find two alternating junctions of bismuth and antimony so that one junction is applied to the body and the other is kept at a uniform temperature. When the one set becomes warmer than the other electricity is generated and this passes to the galvanometer. It is found that when muscle contracts the galvanometer is deflected on account of the current of thermo-electricity. Heidenhain has proved that when a muscle is stimulated by the sudden excitation of its nerve there is an increase of heat in the muscle. According to this the development of heat in muscle represents one of the phenomena of muscle activity. It depends upon the muscle tension, the greater the elongation of the muscle when contraction takes place the more heat is generated; so much so is this the case that when a muscle is stretched to its utmost capacity beyond contraction the greatest amount of heat is developed. It is on account of this that when a muscle is tetanized, the opposing muscles being stretched to the utmost, the muscle is warmed representing the high temperature of tetanus. Heat production in muscle also depends on the amount of work done. If the muscle continues in a condition of contraction bearing up a weight heavy enough to elongate it to its normal length no work is done. During contraction the energy appears as motion but as soon as the muscle is normal again this motion ceases. Thus when the muscle is contracted its energy is in the form of heat, during the contraction it is both heat and activity, thus the heat and the work represent the sum total of energy liberated in the contraction. If a muscle lifts a series of weights gradually increasing to a definite height the heat production increases with the amount of work till a maximal point is reached, when if the muscle still lifts a heavier weight the original height will not be attained. In this case greater work will be done but less of the energy will be given up as heat so that the maximal point in heat production is lower than the maximal point of work performance, "The greater the heat the smaller the work." Even during relaxation a muscle produces heat indicating that the heat production is dependent on the metabolism of muscle. The heat production therefore of a contracting or relaxing muscle represents the metabolic changes in the muscle. The law of the relation of heat and work is expressed as follows, the greater the resistance that is opposed to the contraction the greater will be the amount of mechanical work done. Here of course the stimulation is the important element.

In connection with the activity of muscle the metabolic changes are very important, the nutritive changes themselves representing very important stimuli. When a muscle is at rest and supplied by the normal blood O is absorbed and CO_2 given off, the CO_2 being less than can be accounted for by the O used. A muscle at rest even when deprived of circulation manfests the same interchange preserving its irritability if kept in the air and so provided with a free supply of O. This implies that in the normal resting and living condition the muscle is freely respiring. When contraction takes place the interchange is increased so that during contraction five or six times as much O is used up. Hence the venous blood as it flows from an active muscle is very rich in CO_2. In

the case of muscle tetanus a greater amount of CO_2 is produced than can be accounted for by the O supply, the O supply taking place in connection with combined O in connection with tissue decomposition. In an active muscle blood circulation is freer, more glycogen being used up, such substances as kreatin, urea and uric acid being diminished, water being increased, the muscle becoming acid on account of the presence of lactic and free phosphoric acids, arising from lecithin decomposition. When contraction takes place according to Bernard the blood is kept in the capillaries in the intervening periods, between contractions the blood is poured out into the veins, the smaller blood vessels being distended during contraction. The anabolic processes take place after or between the contractions; when the muscle is contracting the katabolism takes place in the forming of CO_2, H_2O, etc. In an active muscle the blood vessels are always distended indicating quick interchange of materials. When the muscle is resting it is in a chemically tonic condition, depending upon the stimulating effect of the central nervous system.

SECTION III. Irritability of Muscle and Nerve.

Irritability represents one of the properties of bioplasm in virtue of which it undergoes certain definite changes of a physical and chemical nature when subjected to stimulation. It is the capacity of responding to a stimnlus. In order to have this stimulation there must be first of all an excitant which represents something external to the bioplasm and in contact with it more or less complete, so as to excite the muscle or nerve to activity. The excitants have been already classified as chemical, thermal, mechanical and electrical. In normal conditions the physiological stimulation takes place in connection with the nervous system, representing neural activity whether independent of an exciting cause or aroused to activity by some other stimulant. The modulus of irritability in connection with bioplasm represents the amount of activity that the bioplasm manifests when it gives its response to the stimulation, measured by the smallest amount of excitation necessary to arouse the bioplasm to action. In the case of a muscle to which an excitant is applied the amount of contracting taking place as the result of irritation would represent along with the amount of mechanical work that is done in connection with the contraction the result of stimulation. In the case of a nerve there is no observable effect as a result of stimulation, unless we indirectly estimate it from the effect produced on the muscle by the nerve in the case of nerves of motion. Sometimes excitability is used in the same sense as irritability. Irritability is an inherent characteristic of muscle fibre. Haller was the first to discover this property, although Bernard was the first to establish it definitely. He poisoned an animal with curari and then found that by stimulating the motor nerves no effect was produced in the muscles, while by the direct stimulation of the muscles contraction followed. It was objected that irritability depends upon the integrity of the relation between the muscle and the motor fibres as these are inseperably blended together in the end plates. Kuhne found however muscle fibres in which no end plate connection existed and he found that these fibres could be stimulated directly to activity. After destroying the brain of a frog, by ligaturing the sciatic artery in the leg and all the tissue except the nerve and then injecting sub-cutaneously curari into the abdominal region of the body so that the curari is prevented from entering the tissues of the

leg, as soon as the animal becomes completely paralyzed the muscle telegraph may be used in connection with the poisoned and unpoisoned limb. The two sciatic nerves are stretched across the Du Bois Raymond platinum electrodes an induction shock being transmitted in connection with the commutator to the muscle or the nerve. By stimulating the two nerves the muscle in the unpoisoned limb contracts and the other does not; while in stimulating the two muscles both muscles contract. Thus both muscles preserve irritability, although a response may be gained from the unpoisoned muscle by a feebler shock because the nerve terminals are more ready to respond the nerve terminals being irritated and communicating the shock to the muscles. By the use of sulpho-cyanide of potassium irritability is destroyed without interfering with the neural activity. Carbolic acid irritates the muscle but does not affect the nerve. The nerve loses its irritability in three or four days and yet after the section of the nerve irritability may be found in connection with the muscle for several weeks. By exhausting the nerve in connection with repeated electric shocks the muscle is not exhausted so that direct stimulation of the muscle gives a response.

The property of irritability is found in protoplasmic substance which has no nerves, as in some vegetables and in the substance of protozoa, the leucocytes and spermatozoa. Muscle essentially consists of protoplasm and as such possesses irritability which is an inherent property of all bioplasm. Stimuli in connection with muscle represent energy producers. Hence its irritability implies that muscle can be subjected to such stimulation as will arouse molecular changes resulting in the liberation of energy. In this sense stimulation takes place normally through the nervous connection but it may also take place by the mechanical action of probing, percussing, stretching, by the chemical action of water, weak metallic salt solutions or by electric currents. We are not able to measure with accuracy the connection of excitant and excitation, even in attempting to measure the amount of energy produced in connection with a definite irritant this would not give us a perfect knowledge of irritating efficiency. The same difficulty exists in attempting to estimate the relation of different kinds of stimuli to different forms of bioplasm because of the great difference between the cause and effect produced. Yet it is possible to discover the manner in which different kinds of excitants act when they are brought into contact with muscle and nerve. This subject has been studied especially in connection with the cold blooded animal like the frog because of the preservation of irritability after removal from the body. Every part of the body has an independent vitality aside from the general body life, so that when the body life is destroyed the cell life is maintained for a greater or less length of time. It is on account of the resistance of the cold blooded cells that the vitality is preserved longer in the cold blooded animal the vital and chemical changes being more sluggish and therefore not resulting so rapidly in death. The muscle of a frog therefore may remain in an irritable condition for some days after death so that in the study of the phenomena associated with frog muscle and nerve we find conditions that are approximately applicable to the living conditions.

The muscle protoplasm may be directly stimulated although on account of the presence of the branching nerve processes in connection with muscle it is difficult to isolate the muscle from the nerve so as to get the direct effect of stimulation on the muscle. This can be done as we

have said by paralyzing the nerve and the nerve endings by the use of curari. In the sartorius muscle of the frog there are no nerve fibres at the ends the nerve and the muscle fibres being united in the interior of the muscle. At the points of this muscle we find irritability in the bioplasmic substance. In the case of the foetal heart before any neural connection has been developed we find the muscular rhythmic action which indicates the possibility of stimulating the not yet innervated muscle. If a muscle is struck by a blunt instrument the fibres contract at the point of impact resulting in a local swollen condition and by the application of stimulation to the affected part the wave of contraction does not enter into the rest of the muscle which would be the case if the nerves carried the impulses. The muscle itself in this case responds to the stimulation the result being contraction in the muscle alone. This indicates the existence of an independent muscular irritability. The celebrated controversy that arose as to the reality of this muscular irritability has long been settled.

The question is not whether the muscles can or can not be excited but whether they can be excited without that excitation passing to them through the nerves. That this is true is proved by a series of experiments which may be summarized, (1) the sartorius muscle of the frog has no nerves, the cardiac apex has neither nerve cells nor fibres and yet they can be irritated directly; (2) such chemicals as ammonia excite the muscles and do not affect the nerve so that excitation in connection with this chemical substance is direct in the case of muscle; (3) after the motor fibres have degenerated when the nerve fibres give no response in the muscles, on excitation the muscle can be directly stimulated. (4) In connection with the use of curari it can be shown that even after curarizing a nerve it continues irritable and can conduct a nerve impulse indicating that curari affects the neuro-muscular terminal and not either the nerve or muscle separately. This is true in the case of the striped muscle as distinguished from the unstriped, as the nerve terminals in the smooth muscle like the bronchi are much harder to paralyze than the nerve terminals in the regular skeletal muscles or even the cardiac muscles. Hence in the case of striped muscle the curari gives a means of direct excitation, as in the case of the use of electricity upon an uncurarized muscle the current affects both the muscle and nerve if applied to the muscle because it is direct in affecting the muscle and indirect through induction in affecting the nerve. Hence in the use of the voltaic current when the nerves have degenerated a direct current will stimulate the muscles while an induced current does not stimulate them. The voltaic current if passed directly through the nerve if, it remains constant without any rapid change, does not produce any stimulation of the nerve or of the muscle in connection with it. In the case of muscle if the current is passed directly through it there is not generally any excitation, although this is not so true of muscle as of the nerve, particularly where a strong current is used and in this case there is likely to be a tetanic condition produced while the strong current flows. Hence two principles have been laid down in regard to the effect of stimulation by a voltaic current on muscle and nerve, (1) stimulation takes place when the current is opened and closed but not when it is passing, in other words a constant current does not stimulate but if it is rapidly increased or decreased excitation takes place at the opening and close of the increase and decrease. (2) When the stimulation is applied to the muscle or nerve it takes effect only at the point of application and when removed only at the point of removal, the former

representing a stronger influence than the latter. This can be demonstrated in connection with the muscle by taking a long muscle fibre subjected to curari holding it up by its middle and sending through it a current of electricity. If two levers are attached to the ends hanging down with styli the tracings on the kymograph will indicate that the lever at the end of application moves first and the lever at the other end moves only when the stimulation has passed through the muscle, whereas when the stimulation is removed the other end gives the response. This indicates the direct excitability of muscle when subjected to a stimulus and demonstrates its irritability. Longet's experiments confirm this. By resecting the facial nerve its irritability is found to be lost in four days. The muscles supplied by it continued to be subject to stimulation for nearly three months. In other cases it has been found that when muscular irritability is influenced through the nerves it is on account of some nutritive disturbance. If a frog is poisoned by sulpho-cyanide of potassium the muscle ceases to be excitable and the nervous system is unaffected so that even when this is injected subcutaneously the application of stimulation to the nerves produces muscular contraction. When the brain and spinal cord of the frog are destroyed there are no spontaneous contractions, although the nerves continue intact but if a muscle is opened and subjected to stimulation it will contract, the contraction depending on the stimulation, the irritability remaining dormant in such circumstances until stimulated.

Nervous Irritability.—The living corpuscles in the nerve centers and fibres which are simply altered corpuscles possess irritability, that is they respond to stimulation. But in neither of these, that is the nerve centers and fibres does the response take such a decided form as that manifested by muscular corpuscles. A demonstration of nervous irritability may be easily made. If the body of a decapitated frog is not interfered with in any way it will remain perfectly still, while the muscular and nervous tissues gradually lose their irritability and ultimately decompose. But if shortly after decapitation the spinal cord containing the nerve centers is stimulated or irritated in some way certain muscles will contract as is manifested by the movement of the limbs, thus irritability of the nerve centers has in some way or other stimulated the muscles. Again instead of applying a stimulus to the spinal cord if the surface of the body is irritated, for example, by puncturing it or applying a drop of acid then the muscular contraction and movement will also follow. The stimulus applied to the skin has in some way affected the muscles. But before applying the stimulus to the surface if the nerves passing from the integumetn to the spinal cord are destroyed or if the centers in the spinal cord are destroyed or if the nerves from the spinal cord to the muscles are divided, the movements do not take place. Evidently then when the irritant is applied to the cord it stimulates the nerve centers and they respond by stimulating some of the nerve fibres passing from the centers to the muscles called the efferent or motor fibres. The change produced in this way on the nerve fibre is called a nervous impulse and travels along the nerves reaching and stimulating the muscles which respond by contracting. In the case where the irritant is applied to the integument it is clear that it must have produced some change, that is it stimulated the nerves passing from the surface of the body to the centers in the spinal cord called the afferent or sensory fibres. The impressions so produced in connection with the afferent nerve endings and transmitted along them must

have reached and stimulated a center or centers in the cord and as a result of this one or more impressions are aroused in connection with the center and transmitted along an efferent nerve or nerves which stimulate thes muscle to activity, From these facts it is evident that nerve centers may be stimulated, (1) directly or (2) indirectly through afferent nerve fibres; and the nerve fibres may be stimulated (1) directly or (2) indirectly as a result of changes occuring in the corpuscles of the nerve centers.

Of the nature of the changes themselves which take place in nerve centers as a result of stimulation we are ignorant but both centers and nerves possess the property of irritability. If a frog is quickly killed and then the sciatic nerve divided close to the body and dissected out of the body and if the leg is divided obove the knee, in this way we have an uninjured leg and foot with nerve connections. Clamping the bone at the knee and supporting it upwards experiments can be made in connection with the nerve. By mechanically cutting or striking the nerve the muscles of the leg will contract and the foot will move. By the use of acids, alkalies, salts etc. in connection with the nerve muscular twitchings may be produced, these twitchings increasing in intensity as the substance takes effect on the nerve until the whole foot and leg are affected. By the use of hot cautery in connection with the nerves as the nerves become heated contractions take place in the muscle. By connecting the poles of an electric current to the nerve the muscles will contract as the current is applied suddenly and if the current is changed in intensity. In all these cases the nerves are excited by external irritation the muscle being excited through the action of the nerve. No apparent alteration is noticeable in the nerve but the muscular changes indicate that certain changes must have taken place in connection with the nerve resulting in affecting the muscles. This implies that a neural commotion was originated and transmitted along the nerve fibres to a muscle indicating the presence in the nerve of irritability. Nerve irritability does not depend on any perceptible change in the nerve. In connection with the sensory nerves irritability is manifested by sensation, the sensation being in the center, not in the fibre. If the sensory connection is cut off no such sensation will result. If the sensory nerves are intact while the motor nerves are cut the sensation will be found more or less powerful in the center. The nerves are more liable to irritation than ordinary contractile tissue like the muscle, hence the same stimulus will act much more strongly on nerve than on muscle. Hence some physiologists prefer to apply the word excitability to nerves and irritabilty to muscles. In the gray matter of the central system we find both nerve cells and fibres and as these cannot be separated in experiments it is difficulty to distinguish between the irritability of the gray and white matter. It like the rest of the nervous system however is irritable.

Nerves as we have seen are irritable being thrown into a state of irritation by means of stimuli. The stimuli that produce excitation are (1) mechanical. These act on the nerves if applied rapidly so as to produce some change in the neural substance, for example, compression, a blow, division or puncture. When a sensory nerve is stimulated it produces pain, when a motor nerve is stimulated it produces motion associat- with muscular action. If the axis cylinder is destroyed or its continuity interfered with there is an interruption of the conduction of impulses. If the nerve tissue is permanently interfered with then irritability may be lost entirely. Tigerstedt states that the minimum and maximum of

mechanical stimuli are 900 and 8,000 milligram millimeters. If the stimuli are very strong the nerve is exhausted but this may not go beyond the point of application. If pressure is continued in the case of a sensori-motor nerve the motor fibres are more easily affected. If the pressure is applied slowly the nerve may lose irritability without any visible irritation. If the pressure gradually increases in the case of a nerve there is a temporary increase followed by a decrease of irritability. The stretching of a nerve represents mechanical stimulus, if the stretching is slight the reflex irritability is increased but if the stretching becomes severe then there is loss of irritability either temporary or permanent, sometimes producing paralysis. Tigerstedt has invented an instrument the tetanometer by which the strength of the stimulus can be found in the artificial production of tetanus. In the case of a frog's nerve he found the smallest stimulus to be about a gram millimeter. Part of this force is evidently lost as a much smaller electrical stimulus measured by its heat value will stimulate a nerve. (2) Thermal stimulation. By heating the nerve of a frog to 45 degrees C its irritability is increased and after decreased. As the temperature is raised the irritability becomes greater until it reaches 50 degrees C when excitability and conductivity are both destroyed, while if raised to 65 degrees the medulla is also destroyed. The rapid cooling of the nerve to 5 degrees also stimulates the nerve producing muscle contraction. By freezing the nerve its irritability is suspended being restored on thawing. In fact the cooling of a nerve increases irritability especially in the case of a motor nerve although the muscular contractions are not so great. (3) Chemical stimulation excites the nerve if it acts rapidly. The chemical stimulation is manifested in an increased excitability followed by lessened irritation and often paralysis. Chemical stimulation is not so effective in the case of sensory as in the case of motor nerves. By the quick removal of water by the process of drying or by the absorption of water in connection with solutions of neutral salts there is produced a temporary increase followed by a decrease of excitability. Alkalies, mineral acids and organic acids like acetic acid and metallic salts, especially if concentrated, stimulate the nerves, strong neutral potash salts destroying the nerves. Alcohol, ether, bile and sugar first stimulate the nerves and then quickly destroy them. Ammonia, bisulphide of carbon, carbolic acid and some of the metallic salts destroy the nerves without irritating them. The solutions require to be more concentrated in application to a nerve than in application to a muscle in order to get a contraction. (4) Electrical stimulation. Different forms of electrical stimulation may be used, the constant and interrupted current or the induction shock. The current is more powerful when applied and withdrawn than during its continuance; similarly if it is increased or decreased it acts as a special stimulus, whereas, if the current is slowly increased very little effect is produced. Greater stimulation takes place if very quick variations take place in connection with the application of a currant. The induction shocks are more powerful than current electricity and muscle seems to be more sluggish in responding to stimulation, in the case of nerve excitation there is no latent period as in muscular stimulation. In order to the stimulation of a nerve there must be a certain strength of current and it must be applied for a certain time, the minimum according to Fick being .0015 of a second. Even where the current is of longer duration the application of the shock may have no effect at all. The current is stronger in stimulating a nerve

when it runs in the axial direction fo the nerve, if applied transversely it has no effect at all. As the length of the nerve is increased the stimulus required may be lessened in intensity. When the constant current is used in the case of the terminal sensory nerves the stimulation is more marked when made and broken. If the current is strong however sensations may be experienced during the passage of the current. This is not so in the case of motor nerves no effect being produced while the current is passing. During the time the current is passing through a nerve the nerve is said to be electrotonic in which the physiological condition of the nerve is consiberably changed. All parts of the nerve are not equally excitable. Generally the closer a motor nerve is stimulated to the central system the greater is the resulting contraction in the muscle, so that the effect in the muscle is greater the further away it is from the muscle. This led Pfluger to assert that the nerve impulse increases as it comes nearer to the muscle. This, however, depends on the difference in excitability in different parts of the nerve; hence in a motor nerve if the same stimulus is applied near to the muscle and at a distance from the muscle, the latter will give the greater contraction, due to the fact that nerves are more excitable away from than near the muscle, the greatest irritability of a nerve being close to the nerve centers, chiefly because of the trophic influence of the nerve center. This it is claimed does not apply to chemical stimulation as it is claimed that all parts of the nerve are equally excitable by chemical stimuli. Even in the same trunk all nerve fibres are not equally excitable. Weak stimulation of the sciatic nerve of a frog producse contraction in the flexor muscles, whereas it requires a strong stimulation to contract the extensor muscles. In line with this is the principle of Ritter that the nerve fibres which supply the flexor muscles degenerate first, the fibres supplying the extensor muscles degenerating later. (5) Physiological stimulation. The exact nature of the normal stimulation of the nerves is not known. It is called the nerve commotion and travels either centrifugally or centripetally, in the latter case reaching the central organs where it is connected with the production of sensation and perception or is reflexly transferred to the motor nerves, resulting in reflex stimulation. All we know is that a change takes place the external mark of which is an electrical change this change being transferred to the nerve fibre from the neuro-muscular terminal. The physiological stimulation seems to originate in the nerve cell or neuromuscular mass which forms the connecting link between the muscle and nerve in the external organs. The way in which stimulation originates is unknown.

Conditions that Affect or Modify Irritability.—Muscle and nerve are irritable but the degree or modulus of excitability depends on the external conditions found in connection with the irritant and the internal conditions in connection with the muscle and nerve. (1) Conditions associated with the irritant. These conditions are not equally applicable to muscle and nerve some having a greater application to muscle and vice versa. The common excitant used in the case of both muscle and nerve is electricity. There is a danger of injury to the muscle or nerve by the use of the mechanical, chemical or thermal excitants, in addition to the fact that these are difficult to graduate when compared with electricity which can be applied freely if not too strong without any injury and correct graduation of strength, length of application etc. can be made. Galvani in experimenting with frogs suspended by copper wires

found that when the frog was blown by the wind against an iron medium electric currents resulted from which he concluded that electricity existed in the animal the wires being the conductors. Volta corrected this by the discovery that electricity was developed in connection with the contact of the two metals the moist frog tissue forming the medium in which the union of metals took place. On this principle he built up the voltaic pile and from this all modern electrical discoveries have developed. Electricity can now be conveniently applied in connection with the cell elements. If one of the electrodes of such a cell is connected with one end of a nerve and the other brought into contact with the nerve at another point an electric current flows through the nerve from the positive to the negative pole, the result being to give a shock to the nerve producing irritation in the nerve and a secondary irritation in the muscle controlled by the nerve. It is not so suitable to produce excitation by the contact of a nerve or muscle directly with the electrodes, hence the key is introduced to complete the circuit betwen the zinc and copper while the muscle or nerve is in connection with the electrodes, so that by the use of the key the circuit can be opened and closed. When a nerve is connected with a cell there is a temporary excitation unless the current is very strong, the muscle controlled by the nerve giving a single contraction at the moment when the current enters the nerve, so that the current must pass through the nerve without stimulating the nerve. If the current is permitted to flow no irritation takes place but if it is suddenly cut off there is an irritation of the nerve and also of the muscle which contracts. Thus the opening and closing of the current act as quick shocks on the nerve producing contractions corresponding with the opening and closing shocks. The efficiency of the irritation depends on the speed of applying the irritant. If the electric current is constant and of moderate strength the nerve is not excited during the passage of the current but excitation takes place when the current begins and stops. If a current is passed through a nerve, gradually increased or decreased there is no change in the nerve and therefore no alteration in the muscle supplied by the nerve. By the use of the Rheonome an instrument which permits of altering the resistance at will a smaller or greater current can be passed into a nerve. By the use of this instrument it can be proved that if a current gradually enters or leaves the nerve or if it flows steadily through the nerve no change takes place, but so soon as the current is rapidly increased or decreased the nerve is excited. This indicates that it is not the current of electricity which irritates the nerve but the suddenness with which it is stimulated, so that a nerve can be irritated, not by any current strength passed continuously through it but by the alteration of the current strength from time to time. This applies equally to other excitants, hence if compression is gradually brought to bear on a nerve no irritation takes place, this compression if gradually taking place even to the point of crushing the nerve will not irritate it so as to affect the muscle. Similarly chemical action and heat must be brought to bear on the nerve with suddenness if any effective irritation is to take place. Continuous applications of stimuli through the sensory system does not affect the central nervous system, whereas sudden changes like the introduction or removal of light, sudden increase or decrease of temperature do affect the central system. Hence to arouse from sleep there must be some sudden and unusual sound, a principle equally applicable psychologically as physiologically.

In line with this we find that an induced current affects more powerfully the nerves than a primary current, the induced current being intensified by the use of the inductorium. The current of induction is very short, the increase and decrease in the density of the current being very rapid. The action upon the nerves is tested by the result in the muscle contraction. By taking the gastrocnemius muscle and the sciatic nerve of a frog after being dissected out, the limb being clamped in connection with the femur, by connecting the muscle with a light lever connected to a stylus and by stimulating the nerve we get a muscle tracing on the kymograph called a myogram, so that if the nerve is irritated by alternately opening and closing the current a number of movements will be found in connection with the muscle, indicating the contractions taking place. If a direct current from the battery without using the inductorium is used in connection with the experiment it will be found that the opening of the current is stronger than the closing, whereas, in the induced current the closing is stronger than the opening. This arises from the fact that physiologically there are changes taking place in the nerve when the current is opened and closed, these changes differing in the induced and direct currents. The excitation that arises on opening the current is developed in connection with the negative pole of the galvanic battery and that which arises in connection with the closing of the current is developed in connection with the positive pole. This applies equally to the musclee and nerves. By taking a long fibre muscle curarized, for example, the sartorios muscle, and clamping it in the center very strongly so as to hinder the contraction on one side from passing to the other but not so strongly as to prevent the conductivity of the tissue, the recording apparatus is applied to the two ends. The circuit is applied to the two ends of the muscle by the unpolarizable electrodes and by the use of the commutator the current can be easily reversed. It is found that the opening of the current is used to excite the contraction of the muscle beginning at the negative pole, whereas, when the closing of the current was used to excite, the contraction began at the positive pole. When very strong currents are used then the preliminary contractions pass into continued contractions the opening contraction being Ritter's tetanic and the closing one Wundt's tetanic contraction. These continued contractions remain localized in the region of the origin. By the use of the same method in connection with the nerve the same result is obtained, the sudden entering current starting from the negative pole and the sudden leaving current from the positive pole. Bezold experimented in connection with muscle and nerve exciting the nerve by the opening and closing current with the positive and negative poles towards the muscle. When the current was closed with the negative pole at a greater distance from the muscle there was a longer time required than when the current was opened with the positive pole further from the muscle. There is therefore a difference in the nerve and muscle irritated, the current producing the irritation at the points of the poles, the alteration at the negative pole when the current is closed producing irritation that arouses the closing contraction, while the alteration at the positive pole when the current is opened produces the excitation that arouses the opening contraction. The contraction developed in connection with the closing of the current is stronger than that in connection with the opening, hence in all kinds of muscle a feebler excitation can develop irritation at the negative pole while a stronger excitatioa is required at the positive pole. The

closing contraction can be produced with a much weaker current than the opening contractions. This is equally true of the nerves. If a weak current is applied to the nerve, on closing the key there is a single feeble contraction of the muscle and when the key is opened no contraction at all. By increasing the strength of the current slowly as the current is increased the closing contraction is intensified, the excitation arising in connection with the nerve close to the negative pole, when the circuit is broken the contractions take place in connection with the substance close to the positive pole. Thus the closing contraction develops first and only later do the opening contractions develop as feeble contractions gradually increasing. By the still further increase of the current it will be found that the closing and opening contractions begin to diminish so that the current becomes very strong, these contractions ceasing altogether.

Generally as the electric current becomes stronger it has a greater effect on muscle and nerve. By using the induced current this can be proved in the case of the nerve as the current can be altered considerably at will. The force of the induction current depends on the force of the primary current and the distance of the secondary current from it, this being regulated by the mobility of the secondary coil which can be moved away or close to the primary coil. By connecting the secondary coil with a pair of electrodes connected with the nerve in connection with a muscle, the muscle being connected by a lever and stylus with the kymograph, by placing the secondary coil so far from the primary that no effect is noticed on opening and closing the current, and by moving the secondary coil towards the primary a point can be detected where a closing shock excites a weak response while the opening excites none. This will represent the minimum closing contraction. We must be careful not to irritate the nerve too rapidly after a preceding shock and also not to irritate the muscle too much so as to produce fatigue. As the current is increased the closing contractions will increase till a point is attained where no further increase can be secured. This represents the first maximum of the closing contraction. By increasing the current gradually a second maximum may be obtained beyond which no further increase is possible. When the opening contractions are obtained it will be found that a stronger current is required to secure the minimum opening contraction but that after this the maximum opening contraction comes quicker than in the case of the closing contractions. The ordinary current may be used in this connection if the current intensity and resistance are properly gauged by the use of the rheostat which is a box of coils containing wire of a definitely known resistance so that the resistance can be accurately determined. In the same way the current may be increased in connection with the Rheocord which is used for dividing the current so that only a part of the current passes through the nerve. This can be done by increasing and decreasing the resistance as the current will pass along the path of least resistance. In both of these uses of the resistance method it can be easily determined how the strength of the current regulates the irritation, so that the general principle is true, the result of stimulation increases with the increase of the excitant, whether of muscle or of nerve and whether electrical or otherwise.

In connection with the current of electricity it is important to notice that the density is the most prominent factor. In connection with a conductor the electric current spreads over it so that in case of a conductor all parts of which are equal in resistance the smallest diameter will rep-

resent the greatest intensity. Hence in passing a current through the sartorius muscle of a frog the density of the current is greater at the knee and the exciting power will also be greater at that point. If a current is constantly sent through a nerve it does not normally irritate, while sudden changes in the current produce irritation. In the case of medullated fibres there is irritation produced in changed currents in connection with intensity. As the intensity changes there is a greater effect on the irritation of the nerve. All the nerves however do not become irritated by changes in intensity the medullated nerves responding more readily than the non-medullated to short duration currents. In the case of muscles it is found that if the muscles are separated from the nerve action by the use of curari they are very powerfully irritated by the opening and closing of a regular battery current and less strongly by the opening and closing of induced currents. The maximum contraction is greater and of longer duration in the case of a battery than the induced current. In the case of the unstriped muscle this is even more true than in the striped, responding to a direct current if the closing takes some time and only responding to an induced current if very strong. In the case of the unstriped muscle of the ureter the induction shock has practically no effect while the battery current requires to be strong and its closing current must be of long duration. This indicates the important principle of duration in connection with the different forms of the irritated substance, muscle or nerve. In the unstriped muscle the duration of the current must not be less than one-fourth of a second in order to get the maximum contraction, while the striped muscle requires .001 of a second and about the same time is required for the medullated nerves. In connection with currents that last only for a short time medullated fibres give the readiest response, then the non-medullated, the striped and lastly the unstriped muscle and vice versa in the case of the current of longer duration, the intensity changing gradually. This seems to indicate that the more perfect the differentiation of the bioplasm the greater is its mobility under stimulation and the greater its susceptibilty to be irritated. That this does not hold true is emphasized by the fact that in different animals there are different degrees of irritability in connection with the tissues, for example, the striped muscle of a frog gives quicker response than the striped muscle of the turtle. This depends largely on the condition of the tissue, Kries claiming that nerves when cooled give a freer response to slower alterations of intensity, whereas quicker changes give an easier response if the nerve is heated. When the muscle and nerve become diseased or subjected to degenerating changes the stimulation gains a less free response. When a nerve is divided the peripheral part degenerates and although irritability is increased temporarily it is followed by a rapid loss of vitality. In the process of regeneration irritability is only gradually resumed, the response being gained earlier to mechanical stimulation than to electrical stimulation. During regeneration before the axis cylinder is developed mechanical stimuli will receive a response while induction shocks do not. In the case of muscle degeneration the striped muscle assumes the condition of the unstriped, weakly being stimulated by induced currents while direct electrical currents and mechanical stimulation get a ready response. This is of value from a diagnostic standpoint in finding out the condition of a muscle and nerve.

In connection with the current it is important to notice the angle of stimulation. If the current crosses the muscle at right angles to the mus-

cle fibres no irritation results, the power to irritate gradually increasing as the angle is decreased until the current passes parallel to the fibres in their longitudinal direction. The same principle holds good of the nerve. This it is claimed by some depends on the variation in resistance but this could hardly explain the lack of response where the current is applied at right angle to the axis cylinder. Hence it is concluded that when a current is applied to a nerve or muscle at a suitable angle to secure stimulation the irritation aroused by the current is regulated by the changes in the intensity of the current, in connection with alterations in the current's strength and density and the period of application of the current. Changes in intensity have a greater effect on nerves than variations in time. In the striped muscle rapid variations soon lose their effect, being more responsive to currents of longer duration, while in the unstriped muscle the duration is of much importance and quick changes do not call forth any response. In the case of nerves and both kinds of muscle the intensity of the current is the most important element conditioning the response.

In connection with this it is very important that the direction of the current be suitable. In the case of a motor nerve the effect varies according as the current is descending or asending, that is turning towards or moving away from the muscle, the variations being intinsified by changes in the force of the current. In connection with this it is important to remember, that subject to an electric current a nerve is excited close to the negative pole when the current is closed and near the positive pole when opened; that the irritation at the negative pole is more powerful than that of the positive; that while a powerful constant current passes through a nerve conductivity is lessened at the negative pole and lost altogether at the positive, while in removing the current the conductivity is resumed at the positive pole and lost altogether at the negative. Pfluger has given this law of contraction in connection with irritability, in the case of a weak current, both in ascending and descending when the current is opened there is no exitation, when closed there is excitation resulting in contraction; in the case of a moderate current, both in ascending and descending, when the current is opened and closed there is excitation resulting in contraction; in the case of a strong current in ascending when the current is opened there is excitation resulting in contraction and when closed no excitation; whereas in descending when the current is opened there is no excitation and when closed there is excitation manifested in contraction. (A weak current is about 4 milliamperes, a moderate current 10 milliamperes, a strong current 20 milliamperes or over) In new motor fibres from a frog if there is a weak current closing contractions only are obtained in ascending and descending, when the medium current is applied contractions are obtainedin in both directions at both poles, whereas in the strong current the opening of the ascending and the closing of the descending only give contractions.

These investigations and the results have been obtained chiefly in connection with the muscle and tne nerve of frogs but much has been done recently in the application of the electric current to the human subject. In the human subject the current must be applied to the nerve through the skin. In placing the positive electrode on the skin the current is diffused through the skin and tissues passing around toward the negative electrode. The current density will depend on its density in connection with the electrode and also on the conductivity of the tissues through

which the current must pass. Usually where the current is introduced to a nerve through the skin the diffused waves of current will enter the nerve at different angles passing longitudinally along the nerve and then flowing out at about the same angle as that of entrance to reach the negative electrode, some of the current however will pass through the nerve into the tissue and fluids lying around the nerves making different circuits and returning through the nerves again. The electrical electrodes represent a unity but physiologically every point of entrance and exit through the skin represents a physiological electrode so that the electrical electrodes represent a group of physiological electrodes, the positive and negative electrical each representing both positive and negative physiological electrodes. In connection with the effect of the current upon the human nerve, when a current from a battery is closed irritation is aroused in connection with the physiological negative electrode and when it is opened at the positive electrode; the irritation aroused at the negative electrode is more powerful than that at the positive, and the current has the most powerful effect at the point where the density is greatest. In connection with the motor nerves the strength of irritation is estimated from the contractions resulting in the muscle. When the current is closed the resulting contraction represents the excitation aroused at the negative pole, when the current is opened the resulting contraction represents the excitation aroused at the positive pole. Hence in connection with the electrical positive and negative electrodes we find, (a) a closing contraction that is positive or anodal the result of changes in connection with the physiological negative pole under the physical positive pole; (b) an opening contraction that is positive or anodal the result of changes in connection with the physiological positive pole under the physical positive pole; (c) a closing contraction that is negative or kathodal the result of changes in connection with the physiological negative pole under the physical negative pole; (d) an opening contraction that is negative or kathodal the result of changes in connection with the physical negative pole.

(2) Having discussed the relative conditions that determine the value of the excitant, especially in connection with the electric stimulus, we must now discuss the conditions which are at the basis of the irritability of muscle and nerve. The other excitants are determined by similar conditions depending on strength, intensity, density and duration of the irritation and also dependent on the suddenness with which the irritation is applied and the direction in which the application of it takes place. The different irritants affect the nerve and muscle differently so that special conditions arise in connection with the relation of the irritation to the excitement of the nerve or muscle, in other words producing alteration in muscle and nerve irritability. Connected with the power to excite is the power to alter irritability by intensifying it, the state of excitation corresponding with heightened excitability. In the case of bioplasm the irritability depends on the cell constitution and very slight alteration in this constitution whether physical or chemical or both modify the structure and produce a change in irritability. Hence by increasing the irritability there is an excitation of the bioplasm. Therefore we have (a) alteration in irritability and (b) following from this changes produced which correspond with the irritation of the muscle or nerve.

Changes in irritability depend on certain conditions. These conditions involve the four forms of stimuli already discussed in connection with

muscle and nerve, the mechanical, thermal, chemical and electrical. A mechanical blow or a twist or cut irritates both muscle and nerve. If the ulnar nerve is stimulated at the elbow by a mechanical blow the stimulation is at once taken up by a sensory nerve and produces irritation. In the case of a motor nerve of a frog laid bare Tigerstedt estimates that 7,000 mgm. mms. represent the maximal mechanical force necessary to stimulate, representing a very much less force than that generated in the muscle by the stimulation. If the stimulation takes place not too frequently many such stimuli may be imparted to the nerve without tetanic changes, it being estimated that 30 times at intervals of four minutes a nerve can be excited without such tetanus, but if the mechanical blows rapidly follow each other the tetanometer indicates that a series of muscle contractions follow which become blended together resulting in tetanus. By the use of mechanical irritation there is a temporary increase of irritability in the case of muscle and nerve soon followed by a decrease and finally by a loss of irritability. Hence compression increases the power to respond to stimulation but if continued it lessens and destroys it. Similarly the tension of a nerve first increases and then decreases the power of response, the external sheath in this case pressing upon the axis cylinder. Tigerstedt states that tension up to 20 grams increases irritability above that it decreases. This principle is utilized in the destruction of nerves but regeneration may take place later. Muscular irritability is increased by medium tension and destroyed if it becomes excessive. This is evident in connection with the tension of any of the muscles of the body which become much more liable to irritation in this condition.

Thermal changes, if these changes are rapid and extreme, produce nerve and muscle irritation, hence the rapid freezing or placing in very hot water of a muscle or nerve produces excitation resulting in muscular contraction. If the arm is placed in cold water as soon as the water penetrates the tissues and reaches the nerve there is stimulation resulting in a feeling of pain, followed by a numb feeling which represents the lessening of irritabilily and its gradual loss. If on the other hand the cooling or heating takes place gradually there is no excitation, even if the cooling or heating are carried to the extent of destroying the vitality of the substance. Hence in the case of a brainless frog it is said that if placed in a vessel of water gradually heated to the boiling point no movements will be noticed, indicating that no irritation takes place. Hence this is called thermal rigor which in the case of frogs takes place about 45 degrees and in the human subject about 51. Hence to raise the body temperature or to lower the body temperature increases or decreases the irritability, the heat and cold if excessive and continued for a long time having the effect first of lessening and then destroying the irritability. There is a difference however between extreme heat and cold, in the former case the chemical alterations are increased so that there is little power of resistance left in the tissue, while in the latter the chemical alterations are lessened and there is an increased power of resistance. Hence the cooling of the muscle or nerve tends to preserve irritability provided that it is not extreme or long continued.

When the composition of muscle and nerve is altered there is a corresponding alteration in its irritability, hence to remove a muscle or nerve from the body and place it in a foreign fluid or to inject a foreign fluid into the circulation through the muscle results in altered irritability. This is particularly noticeable if an excess of salts is present while the ab-

sence or presence of proteid substance does not seem to affect them materially. In the case of dogs the effect is noticed in a temporary increase of irritability followed by a lessening of irritability, motor nerves being more liable to alteration in this respect than sensory. If the change is rapid there is excitation but if slow there is none. Increased irritability is often associated with excitation, the muscle exhibiting quick contractions as the nerve fibres become more or less affected. The injection of water into the circulation produces stimulation resulting in contraction after a time, irritability decreasing; CO_2 and the acid phosphates of potassium decreases the irritability. NaCl solutions of .6 percent were formerly supposed to have no effect on nerve and muscle irritability but it has recently been found that this produces increased irritability followed by lessened irritability, possibly because of the production of CO_2 or from the exhaustion of other salts necessary to the irritability of the tissue. In order to mantain normal irritability therefore there must be a definite chemical composition, very slight alterations of the component elements producing deviation from the standard of irritability. In the lessening of irritability it is noticeable that there always precedes it an increase of irritability marking the first deviation from the normal, exhaustion soon following and the entire loss resulting later.

As we have seen by the use of a constant current of electricity passed through a muscle there is a single short contraction when the current enters and leaves the muscle. By the use of a strong current when the contraction leaves the muscle there is a lengthened tetanic contraction and if the current is broken there is a lengthened tetanic contraction following the opening contraction. As we found before if a very feeble current is used there is no noticeable contraction although it exercises an influence on the muscle while passing through it. There is a latent irritation taking place at the negative pole which gives rise to an increased irritability of the muscle. when the current is withdrawn the muscle at the negative pole is exhausted and therefore will be lessened in irritability. At the positive pole while the current is passing there is lessened irritability and on removing the current it manifests increased irritability. If a frog's heart is taken and the positive pole is placed on the ventricle while the negative pole is placed at some other part, at each contracting of the ventricle there is relaxation at the positive pole the result being that the part at the positive pole is pressed out and forms a vesicle.

The effects upon the nerve are similar to these on the muscle except that when the changes take place in connection with the positive and negative poles it is not so definitely confined to the local region but there is a greater spreading of the irritation in the region between the poles. Muscle and nerve are said to be electrotonic under the influence of electric stimulation, the electrotonic condition being marked in two directions, physically manifested in changes in the electrical condition, and physiologically in the resulting changes in the irritability of the tissue. Pfluger has investigated this subject very fully and finds the electro-tonicity greatest in contiguity to the positive and negative poles, the diffusion of influence taking place in all directions from these points. The change taking place in conection with the positive pole we call anelectrotonic and that in relation to the negative pole katelectrotonic. These altered conditions of irritability are found not only in the nerve between the point of application and the muscle but also towards the central side. This electrotonic condition is greater if the nerve is in proper condition and as the

current becomes stronger the nerve is influenced more thoroughly by it. In the intervening region between the positive and negative poles there is a point where irritability is unaffected because the positive and negative influences when excited extend a definite distance, the intervening part being indifferent. When the constant current passes through muscle and nerve there is an important after affect, hence if during the passage of the current irritability is increased there is a following decrease of irritability and the reverse is also true. By the closing of the current irritation originates from the negative pole and when it is opened from the positive pole, indicating that irritability has been changed, the excitation being aroused only when irritability is increased so that it is almost impossible to distinguish between increase of irritability and excitation. Thus we find that where irritants are brought into relation with the muscle and nerve there is a change in irritability provided the irritant is properly conditioned. The condition seems to be generally sufficient force and sufficient duration. In the case of a muscle a weaker irritation may produce an effect on irritability if it is produced frequently. Thus in the case of muscle there may be an accumulation of the after effects of frequently and rapidly applied shocks which in the end give a contraction although the individual shocks give no result. When the irritations follow each other with sufficient rapidity the resulting effects cease to be single and form a series of continued after effects called tetanus, the contraction being greater than during a single contraction. This does not depend on heightened irritability.

In mantaining the normal physiological condition of the muscle and nerve the most important condition is that of a regular and properly regulated supply of blood to the tissues. In the circulation we find the means of establishing the relations between different parts of the body, in the different tissues and also the interchanging medium for the exchange of material. Hence the nutrient matters including O are carried from the alimentary organs and the lungs to the different tissues of the body and the waste products are carried off to the organs of excretion. In connection with the blood we find also the special function of neutralization, taking place in connection with the acids arising from cell activity, preserving the immune alkaline reaction of the blood which is the basis of the blood vitality. In the same way it provides the fluid exudation that moistens the different tissues, assisting and promoting the osmosis in connection with the different tissues so as to mantain the normal chemical composition of muscle and nerve. This blood circulation passing through important chemical changes in its progress through the body has an important bearing on muscle and nerve irritability. In the muscle we find continuous changes taking place resulting in the setting free of energy, this energy varying whether the muscle is resting or active. In order to continue cell activity there must be a constant replenishing of materials, one of the large supplies necessary being O in order to carry on oxidation in the tissues. If we take a rabbit and ligature the abdominal aorta the blood will be kept from circulating in the limbs and also in connection with the spinal cord, resulting in a paralytic condition of the lower limbs with the loss of feeling and the loss of all mobility. This paralytic condition arises from the destruction of the function of the nerve cells in the spinal cord so that no stimulation can be aroused and no impulses communicated to the muscles. Very soon if this is continued the peripheral nerves and the muscles controlled by them lose their irritability, the motor nerves giving up first.

This is found clearly in the fact that by applying artificial stimulation to the muscle or the sensory nerves while the muscles respond there is no response through the nerves, indication that the neuro-muscular terminals have ceased to be irritable. The relation between muscle and nerve is very close and this relation is soon disturbed, it being claimed that within 20 minutes after the ligature the muscle cannot be excited through the nerve whereas the muscle preserves its own independent irritability for six or seven hours. The loss of muscular irritability depends on tissue respiration so that as soon as tissue respiration is interfered with, for example, in the withdrawal of O from the muscle, the muscle is thrown upon its own resources and these resources are not available if the muscle is clogged by the waste matters that cannot be thrown off such as CO_2. Thus the lack of O and the presence of CO_2 in the muscle lessens irritability. The relation of the nerves to the blood supply is as yet imperfectly understood. The nerve is closely connected with the cell for the trophic influences. The relation of the nerve to the blood supply however is of great importance. In order to preserve nerve irritability there must be a constant supply of fresh blood as the nerve fibre will not continue irritable long if O is withheld. If a nerve is taken from the body and preserved in O it mantains its irritability longer than if kept in the open air; and if it is kept in a mediumfrom which O is extracted it rapidly loses its irritability. Similarly the presence of such waste matters as CO_2, lactic acid lessens irritability. It has been found that it is possible to preserve the irritability of muscle and nerve after death by artificially supplying to the muscles a circulation of blood defibrinated and oxygenated and kept moving in the muscle preserved at a normal temperature and free from CO_2. Frey succeeded in preserving the vitality in the muscles of a dog for seven hours in this way and similar experiments have been successfully made in connection with the heart, the heart supplied with defibrinated blood being kept pulsating for five hours. The supply of blood to the muscle and nerve is regulated by the needs of the tissues. By the stimulation of the muscles to activity the blood vessels are distended. In the case of muscle exercise the cardiac and respiratory activity are increased so that there is an increase of blood to the tissues.

In connection with nutrition it is important that the nerves and the muscles regulated by them are kept in close connection with the central nervous system because from the central system trophic influences emanate. If a motor nerve is injured or cut so that conductivity is suspended degeneration rapidly takes place away from the central system. Every motor fibre is a branching process from a motor cell in connection with the anterior cornua of the spinal cord. If such a process is cut off from its cell there is a temporary increase of excitability greatest at the point of division, the increased excitability passing down the nerve towards the periphery followed very rapidly by a decreased irritability in the same direction. So soon as the axis cylinder loses its normal chemical constituents the physiological structure begins to give way, the result being finally complete degeneration of the nerve, followed by the same degenerative changes in the motor plates. Very soon the muscle begins to fail in irritability although no change is noticeable in the physiological structure of the muscle. The nerve loses irritability in about four days, the motor plates in about nine or ten days and the muscle begins to show lessened irritability in 14 days, after which there is an entire change the

muscle becoming assimilated to the unstriped muscle form, indicated by the lessened response to induced electric and the increased response to mechanical and direct current stimuli. This continues to increase for about 40 days when the maximum is reached, after which the irritability begins to lessen gradually, being lost entirely in from three to seven months. This loss of irritability depends on degeneration changes both in the muscle and nerve resulting in destruction of tissue. Some regard it in the case of the muscle as due to the absence of stimulation trophically from the central system, while others regard it as due to vaso-motor disturbance resulting in the improper control of the blood supply. The latter can not be the true view because even when the nerves of vaso-motion are intact there is the same loss of irritability when the motor connection is cut off. In support of the first view it is claimed that where electric stimulation is substituted the degenerative changes may be postponed for a considerable time. The trophic influence of the central nervous system certainly has something to do with muscle tonicity and the preservation of the balance of the katabolic and anabolic changes of the muscles.

When the muscles are active they may be over-exerted and this may result in fatigue. This fatigued condition is characterized by the diminished irritability, diminution in the muscular contraction and lessened energy with a much greater diminution of the rate of contraction and relaxation. Any cause that produces any of these results may be called a producing cause of fatigue but the term is limited to that condition which results from excessive activity resulting in over exertion, the after effect being fatigue. In the case of over exertion the results are very much the same as those found associated with the muscle and nerve when through excessive stimulation there is a loss of irritability and a diminished power of responding to stimulation. Hence fatigue represents a condition which is analogous to that induced in the muscle and nerve by ligaturing the blood circulation. The active cell sets free energy on the basis of the supply of nutrient matters including O so that as the oxidation changes take place resulting in the throwing off of the waste matters there is activity developed. Hence in the case of fatigue there are two phases in the production of it, the lack of energy producing substances and the accumulation of retarding elements in the waste. The cell activity depends on the supply of nutriment so that if this supply is readily exhausted then the fatigued condition soon comes on. By the strong and rapid contraction of a muscle this exhaustion takes place readily, whereas if the contractions are short and less vigorous, at greater intervals between the contractions, then the endurance is greater and the fatigue is postponed. In the case of the heart we find normally about 72 contractions taking place per minute and yet although these are kept up continuously during life there is no fatigue or exhaustion resulting. This is accounted for by the fact that after each of the systolic contractions there is a comparatively long diastolic rest during which the muscle is able to recover its normal irritability. By taking the abductor muscle it has been found that contraction taking place slowly and without any strain can be continued by lifting a small weight in connection with the finger almost 10,000 times inside three hours without inducing any fatigued condition of the muscles. By either increasing the rapidity of contraction or the amount of the weight producing the contraction it is found that the muscle becomes very quickly exhausted. In this case with the in-

crease of the weight the contraction periods become briefer and the resting period is also lessened so that the muscle has no time to recover itself from the effects of the contraction activity. Mosso has found that in the case of each muscle there is an individual coefficient of endurance so that a definite amount of force in connection with the contraction and a definite period of duration for the contractions are necessory in order to sustain the normal irritability and prevent fatigue. If either the force producing the contraction is increased or the period intervening between contractions is lessened then there is lessened capacity for work and consequently fatigue results. In the case of walking exercise we find that different muscles are brought into play so that while time is given to one set of muscles for rest during the activity of the other set of muscles there is an equilibrium preserved between the two sets of muscles. Even here however there is a limit to endurance because after a definite time the muscles become exhausted and not only the muscles that are especially active but other muscles that seem to be kept quiet, as for example the muscles of the arms, begin to yield to the lessened irritability.

This seems to point to the fact that fatigue while it may be local is rather general than local. This is easily understood if we remember that there are two forms of direct connection in the case of all the muscles, namely the circulation of the blood and the nervous connection. By the circulation of the blood every minute part of the muscular system is closely connected with every other part. In circulating through the system the blood carries materials to the different tissues and if the materials are taken from the blood by one muscle these cannot be left for the other muscles. The same thing is true of the waste products given off by an over active part of the body so that the blood establishes a sympathetic relation between all the different muscles whether active or resting. This is increased if we remember that the nervous system presides over the changes in the muscle, the circulation and distribution of the blood, so that any changes in one part of the muscle system have a bearing upon the entire body through the close nervous connection of all the parts. It has been found in the case of soldiers when required to make very long and tedious marches that it is not sufficient to keep them well supplied with food, for this will not compensate for the body loss through overexertion. The taking of food only partially recovers the fatigued muscles rest being as necessary as food. Mosso claims that this is due to the accumulation of the waste products in the system, time being necessary to remove these in connection with the blood circulation. Taking a dog that was fatigued he withdrew a certain volume of blood from its circulation replacing it by an equal amount of blood from a resting dog finding no appreciable effects; he then took the blood from the fatigued dog and put it into the resting animal and found that in the case of the resting dog all the evidences of fatigue were present and sleep was induced. Hence he concluded that the waste matters from active muscle passing into the blood circulation affect the irritability of all the muscles of the body. Mappiora continuing Mosso's work has found that when special sets of muscles are fatigued the supplying of food does not restore irritability in these muscles but that rest is also necessary. He found in the case of the arm exhausted in lifting weights that about two hours is sufficient to restore the exhausted muscle to its normal condition. He also found that by increasing the circulation of the blood and lymph by the use of massage the restoration of the muscles took place more rapidly

Here we find the physiological significance of the Lomi-lomi of the Sandwich Islands. Lying down on a mat the muscles are worked over by strong hands not vigorously but slowly, from head to foot, all the tired muscles being kneaded in such a way as to promote a free circulation of the blood and with it a free carrying away of the fatigue products.

This seems to indicate that when the muscles are fatigued they are not able to give off with sufficient rapidity the waste product, even though the blood circulation is increased during the activity of the muscle. This however may be due to the fact that vaso-motion alters the muscle condition and especially the condition of the muscle walls of the blood vessels as soon as activity in the muscle ceases. During muscle activity the nerve impulses of vaso-dilatation distend the arterial walls permitting a free circulation, but as soon as the muscles become inactive these impulses cease to be sent to the vessel walls and the result is that the vaso-constriction impulses contract the vessel walls so that the blood circulation is diminished. In ordinary circumstances this is sufficient but when the muscles are exhausted then we find that the circulation is not sufficiently great to carry off the waste. In normal conditions the muscles never become exhausted. When the muscles are overexerted stimulating impulses are sent up to the nerve centers and a greater demand is made upon these nerve centers, with the result that the nerve centers are more quickly exhausted than the muscles. While the nerve cells become exhausted more rapidly they also more rapidly recover their normal irritability so that they can act upon the muscles again. This represents one of the advantages in the difference between nerve and muscle irritability and endurance. If the nerve irritability lasted longer than muscle irritability then the nerve impulses would continue to draw on the muscles until complete exhaustion took place, whereas, the nerve economizes muscle irritability by more readily using up its own. It is for this reason that when muscle irritability is being lessened there is associated with the muscle a feeling of pain representing nervous exhaustion and indicating the danger mark in the case of effort, so that as it requires a greater effort to continue the muscular work there is the tendency to cease working and give an opportunity to muscle and nerve to recuperate. If the active effort of the muscles is prolonged beyond this period then there is produced a condition in the muscle that requires a long period for recovery.

Not only is muscle exhausted but every form of bioplasm is subjected to exhaustion by long continued and frequent application, resulting in the lessening of irritability and the loss of a certain amount of functionality. In the case of a nerve while it is true that a condition of fatigue is induced it seems that the fatigued condition does not represent the same state of matters in the nerve as we find in the muscle. Muscle activity is represented by contraction while contractility does not characterize the nerve. Neural work consists chiefly in conductivity so that the working condition of the nerve represents the transmission of impulses. By the application of irritants to the nerve the nerve irritability may be changed but where this is produced in the nerve it does not correspond with fatigue but rather depends on the change taking place in the molecular substance of the nerves. Hence if fatigue takes place in the nerve it seems to take place from the nerve cells, the fibres being regarded as processes from the nerve cells and therefore whatever influences the cell will influence the fibre. We know that the nerve cells become fatigued by the action of

strong and oft repeated stimulations so that it is reasonable to suppose that the exhaustion of the nerve takes place in connection with the cells. While it is true that fatigue is characteristic of muscle and nerve tissue all kinds of tissue do not become subject to fatigue to the same extent. Hence some forms of tissue can liberate energy for a long time without showing signs of exhaustion. This represents the first step in the failure of irritability, namely, when the tissues begin to lag in response to stimulation.

This law has been laid down that the greater the irritability the smaller the endurance of the muscle. When the irritability is heightened there is a greater amount of energy set free on irritation, leading sooner to exhaustion. Hence in the case of a rabbit the white striped muscle responds very rapidly to irritation and is soon exhausted, while the red unstriped muscle responds very slowly and lasts longer. Even the same muscles in different individuals possess different degrees of irritability and endurance this being due largely to the use or non-use of the muscles. Hence use of muscles within normal limits increases the strength of the muscle and also its endurance. This is due largely to the fact that where the muscle is in active use the circulation is more perfect so that by the efficiency of the circulation the muscle cell becomes educated to a quicker and more refined activity in utilizing the nutritive materials and throwing off waste. Muscular exercise produces an increased growth of muscle fibre and also introduces greater mechanization in muscle metabolism so that greater economy is found in the use of material and in the liberation of energy. In the case of nerve cells any kind of work tends to exhaust the stored up energy and to induce fatigue. Hodge killed cats after a day of activity and others in the morning after a night's rest finding that the nerve cells of the former were much smaller than those of the latter.

There is a closer relation between muscle fatigue and the fatigue of the central nervous system than is commonly supposed. Donaldson says, "in the last stage of extreme fatigue it is the nerve cell not the muscles which are exhausted." The energetic activity of the muscle has a rhythmic variation during the day depending on the control of the central nervous system, hence at certain times there is attained a maximum in the energetic capacity of the muscles. According to the experiments of Lombard the maximum is from about ten to eleven a. m. and p. m. and the minimum from about three to four a. m. and p. m. This fact of fatigue has an important bearing on exercise and its value in strengthening muscle and nerve. Halleck says, "nutrition of the best kind depends on the state of antecedent fatigue." If the muscles or nerves have been exercised up to the point of fatigue, not to over exertion, they are in the best condition for being nourished. Both nerves and muscle should be exercised to the point of fatigue so as to be in good shape for assimilating nutriment and building up the tissues. The bearing of irritability on exercise has not yet been fully investigated. Each tissue whether muscle or nerve has its own modulus of irritability and the exercise of this irritability if not carried to the point of exhaustion has an important bearing on the development and strengthening of irritability. And here the central system has a greater influence on the irritability of muscles than we can yet explain because the exerciseof the muscles involves the exercise of the nerve cells. Hence for training not only must there be a careful muscle training but also a careful, well proportioned and adequate nervous training. The relation is so close between the muscles and nerves,

especially in the sensory and motor end organs, that no influence can affect the one without affecting the other.

As use and exercise tend to strengthen the muscles and nerves so disuse tends to weaken them. This applies to the body as a whole or to the individual parts, so that a resting limb or a resting body becomes enfeebled through enforced rest. This arises partly from the fact that the blood circulation is diminished and partly from the inherent muscle properties that give a response only to stimulation, muscle activity not being in any sense automatic or auto-motor. Hence muscle irritability may be intensified or preserved for a considerable length of time when lessened, by and normally it may be said to depend on, (1) an increased blood flow. By dividing the lumbar nerve on one side of a frog the vaso-motor fibres become paralyzed and the capillaries are distended, resulting in increased irritability on the side of of injury. Similarly by dividing the medulla on one side there is an increased volume of blood to the brain, resulting in increased irritability and this extends to one half of the body. The adequacy of the blood flow determines the normal irritabilty. The better the circulation, the freer the removal of waste, the more perfect the irritability. The relation of the circulation of the blood to irritability has been illustrated by Brown-Sequard. Thirteen and one-half hours after the decapiiation of two men when rigor mortis had set in, he injected fresh human defibrinated blood into the arteries of one hand allowing it to flow into the veins; reinjections were made from time to time during the next half hour, with the result that excitability returned in the muscles of the hand, only two of the muscles not being excitable.

(2) When a muscle is exhausted a period of inactivity or rest will recuperate the muscle and restore its irritability. Rest is so necessary that if a muscle does not enjoy rest it will soon become everexerted. (3) The presence of O is necessary in order to preserve irritability. If a limb is entirely cut off from its connection with the body and a volume of oxygenated blood is injected into it irritability will be increased. The exhaustion takes place more rapidly in the nerve than in the muscle for after the nerve ceases to give any response there will be a response given by the muscle. The modification of the irritability in the muscle and nerve depends as we have seen on a number of circumstances all of which are associated with the vitality of muscle and nerve If a muscle inside the body is deprived of its blood supply by ligaturing the vessels there is a gradual diminution of irritability and finally the characteristic rigor mortis condition is induced. When the blood supply is cut off by the cessation of the circulation the same result follows. In connection with the rigor mortis condition we find a regular order in its coming on in connection with the muscles first it appears in the muscles of the jaw and neck, next in those of the trunk, next in those of the arms and legs. The rapidity with which this rigor mortis comes on after death depends on the condition of the body and the external circumstances, for example the warmth of the external atmosphere hastens it while cold delays it. (4) Stimulation either in the case of feeble shocks or of a continuous feeble electric current passed through the muscle longitudinally will aid in preserving and in securing irritability. (5) Temperature has a great effect on irritability and on the muscle contraction, the maintenance of the normal temperature assisting in preserving irritability. Diminution of irritability may accompany an increase of temperature above a certain standard. Sudden heat or cold brought into contact with a muscle or

nerve acts as a stimulant, for example, if a muscle is gradually cooled to zero C there may be no stimulation but as soon as it reaches 51 degrees in the mammalian muscle there is thermal rigor resulting from a forcible contraction. A moderate degree of heat assists in preserving the irritability of muscle and nerve by favoring the molecular processes. As a result contraction is secured more rapidly because of the rapid chemical changes taking place and as the materials to supply the muscle are rapidly exhausted there is a quick loss of irritability. If cold is applied gradually to a nerve there are different results depending on the nature of the stimulation, all the molecular processes being retarded, so that the undulatory nervous impulse is diminished and the rate of conductivity is also diminished. (6) The functional use of the muscle promotes irritability. If a muscle is not used it degenerates but if it is used inside normal limits it grows. This indicates that muscle nourishment is improved by functional use. This may be partly due to the increased circulation of blood that is found when a muscle contracts. By the stimulation of a nerve to a muscle dilatation of the blood vessels takes place. Hence during contraction more blood is caused to flow through the muscle and this increase of blood continues even after the contraction has ceased. Aside from this, however the exhaustion that results from contraction seems to give rise to a reaction that assists the nutrition of the muscle. This forms the principal reason why in the use of a muscle it is increased, in other words, the loss that is sustained is compensated for by the increased muscle metabolism that takes place while the muscle is in a resting condition. As we have seen when a muscle has been actively used its irritability is diminished but this is only temporary because the functional activity promotes the further development of the muscle. In the case of a motor nerve it seems to be almost impossble to induce fatigue by stimulation. When an animal is given curari stimulation of the sciatic nerve may take place without interruption for several hours without any loss of irritability. The muscles do not contract because the curari protects them from the influence of stimulation, but when the curari effect passes away contractions begin in connection with the stimulation of the sciatic, indicating that the sciatic nerve has not become exhausted. In the case of the nerve the molecular processes which are at the basis of nerve commotion are of such a character that so soon as one impulse has been developed the nerve substance is capable of developing a new impulse. The feeling of fatigue is complex both in its origin and in its nature. Possibly it originates in connection with certain changes in the muscles but it certainly is increased by the action of the nervous mechanism and especially by the connection of the central nervous system. This indicates that the fatigue is not localized entirely in the muscles, as in the case of a tired individual there is still capacity for work in connection with overexertion, the recovery taking place in connection with the normal blood renewal and the normal rest of the muscle. If the contractions follow each other quickly the exhaustion is more complete. When the muscles become exhausted there is a diminution of elasticity as the fatigued muscle does not return very readily to its normal condition. This fatigue that arises in connection with contraction may be produced either by the using up of the stored up material found in connection with the muscle or by the accumulation of certain products of contraction in the muscle. During the restoration of the normal muscle condition there are certain internal changes in connection with which new materials are

formed and the waste products are thrown off. It is in connection with this restorative process that fresh blood and sufficient oxygen are necessary.

The diminution of irritability or its destruction may be accomplished, (1) by the stoppage of the circulation; (2) by the overexhaustion of the muscle; (3) by the presence of large quantities of foreign substances, such as CO_2, lactic acid, phosphate of lime, etc.; (4) by a temperature that is much below or above the normal body temperature. A tempera-approaching zero C lessens irritability but does not destroy it. A high temperature approaching 30 degrees C increases irritability, produces fatigue and if it reaches 35 degrees C in the case of a frog's muscle it is found that irritability is entirely lost. When the circulation is stopped and the nerves cease to exert an influence on the muscle irritability is lost soon, the periods varying from a few hours to several days. During life irritability may diminish for weeks and then gradually disappear, while after death, in the case of the human subject, it usually disappears in four or five hours, although in some cases it has continued for 24 hours, the cardiac muscle being the last to yield up its irritability.

In connection with the sensitive fibres the irritability of these fibres manifests itself in the sensation that is associated with the nerve centers. The result of the stimulation of sensory fibres has not been very fully investigated but it seems to be regulated by the same laws which regulate motor nerves. If a sensory nerve is stimulated the effect must be determined by the stimulation that results. In the case of the motor nerve the electric condition may be associated with resulting contraction in the muscle; similarly by the stimulation of the sensory nerve there may or may not be a resulting sensation, the nature of the sensation being liable to very great variation. In order to secure a definite result in sensation two conditions seem to be necessary, (a) there must be a connection between the nerve and the nerve center; and (b) there must be irritability in the nerve. Irritability in the sensory nerve may be so lessened by pressure or by the results of chemical or thermal stimulation that no result can be secured by the application of stimuli. In the case of the ulnar nerve it has been found that to apply extreme cold at the elbow results in the complete loss of sensibility in the part supplied by the nerve. Irritability in a sensory nerve may be lessened by injury, as for example the division of certain portions of the brain or of the spinal cord may result in the loss of sensation in special parts of the body and these may disappear in a short time. It has been found that by the division of one sensory nerve there may result the suspension of sensory fibres in contiguous nerves. There may be also an increase of irritability in a sensory nerve by injury or by a large blood supply amounting to a congested condition. For example the cutting-off of the blood supply by ligaturing the arteries may, first of all, produce in the nerve an abnormal excitability evidenced in pain and then later produce the loss of sensation. The presence of irritability in sensory nerves during life is manifested in sensation and it continues to exist even after death in connection with reflex actions.

In connection with the motor nerves we find that irritability can be easily studied because when stimulated there is a resulting muscular contraction. This stimulation and the contraction resulting may be found even after the nerve and the muscle have been removed from the body. Normally however two conditions are necessary, (a) irritability must be preserved in the nerves; and (b) there must be power in the muscle to

respond to stimulation. We have seen already what is involved in the existence of muscular irritability. In the case of a single muscle fibre in connection with the microscope we can see the contraction taking place after the separation of the fibre from the rest of the muscle. In connection with the stimulation of a motor nerve we have seen that the effect is most apparent when a current is allowed to flow into the nerve and when it is suddenly broken. Muscular contraction is under the influence of nerve irritability. The irritability of the motor nerve continues until after death. This is evident from what we have said already in connection with the stimulation of the sciatic nerve in connection with the limb of a frog. If in the case of a frog's leg with the sciatic nerve still in attachment it is kept cool the nerve will continue to be irritable for a considerable time. If on the other hand it is stimulated repeatedly it will begin to act with decreased activity and before long will soon cease to respond. If after this it is allowed to rest irritability will be partially restored. This may be continued for a considerable time provided resting periods are given to the nerve at each repetition, however the nerve becomes less irritable and this diminution of irritability will continue until it is entirely lost. Motor nerve irritability may be suspended or lessened by pressure, by the application of cold or by the use of anything that will diminish the power of controlling the muscle. Sudden injury of the nerve will have its effect as in cases where there is a diminution of the power of motion by extensive injuries to the human limbs. In this case there is a disturbance first of all in the muscular system which results in a shock to the nervous system, the shock being greatest in the central nervous system so that from the central system reaction takes place in the motor nerves diminishing muscular contraction and nerve sensibility and lessening both nerve and muscle irritability. If a current of electricity travels along the nerve in the same direction as the fibres, for example, in the motor nerve from the center to the periphery the current is said to be direct, whereas if it passes in the opposite direction it is inverse. If the nerve is very irritable or if the intensity of the current is very great there will be a resulting muscle contraction both at the beginning and ending of the current whether the current is direct or inverse. If on the other hand the nerve activity has been lessened or if the current is feeble there will be a response manifested in contraction only at the beginning of the direct current and at the end of the inverse current. By preparing the two hind legs of a frog so that they still continue united together by the sciatic nerve and a part of the spinal cord, if the negative efectrode of a current is placed in connection with the left foot and the positive electrode in connection with the right foot, the electric current that passes through the sciatic nerves will be inverse for the right nerve and direct for the left. When the current circuit is completed there will be a resulting contraction in the left and not in the right leg. On the other hand when the current is removed there will a resulting contraction in the right leg and none in the left. If a nerve is exhausted by the use of the direct current it will still respond to the inverse current; and if it is exhausted in connection with the inverse current it will still be sensitive in connection with the direct. It has been found that even when a nerve is for the time exhausted in connection with the direct current irritability is restored more readily by the use of the inverse current, in this case returning to its normal condition more readily than if allowed to rest. From this it is evident that to change the current from direct to

inverse and from inverse to direct has the effect either of resting the nerve or of assisting it to recuperate itself. This indicates the special value of the quickly alternating currents of induced electricity.

The irritability that is associated with the motor nerves is independent of that of the muscles. This can be proved by the fact that the irritability may be suspended in each case independent of the other. In connection with the use of curari the action of the motor nerve is suspended without a suspension of the muscle irritability. When a frog has been poisoned by curari, if the current is applied to the sciatic nerve there will be no response in connection with the muscle, but if the current is applied directly to the muscle there is a direct response. The same thing is proved by the fact that nerve irritability yields before muscle irritability. This is also indicated by the results that are found in connection with degeneration. On the division of a motor nerve the divided part loses its irritability so that when stimulated there is no muscle response. The application of a direct current to the muscle will give a response so that the irritability of the muscle and of the nerve must be regarded as independent.

As we have seen the result of nerve action in the sensory nerve is different from the result of nerve action in the motor nerve, in the former case a sensation is produced, in the latter case a peripheral muscle contraction. If a sensory nerve is divided and its central end is stimulated a sensation may be produced, no such sensation resulting from the stimulation of the peripheral end. If a motor nerve is divided stimulation of the end still connected with the central system gives no result while the stimulation of the peripheral end gives a muscle contraction. This indicates that the nerve commotion in a sensory nerve moves centripetally and in a motor nerve centrifugally. The result of the stimulation of a sensory nerve is never anything but a sensation and that of the motor nerve never anything but movement. These facts indicate that the sensory and motor fibres are independent in their modes of their activity as well as in their neural properties. This however does not prove a difference in the kind of activity but only in the result of the activity, because in neither case do we know that there is any susceptible change in the nerve; all that we do know is that in the organ with which the nerve is connected there is some change. When a sensory nerve is stimulated the sensation is in the center; when a motor nerve is stimulated the contraction is in the muscle. In both of these cases the action of the nerve may be the same and this seems to be the conclusion that physiology would point out in connection with the two forms of nerve irritability.

There are several reasons for this physiological conclusion. (1) when a nerve is stimulated, whether it is sensory or motor, the same effect is produced throughout its entire length. When impressions are made on the skin a nerve commotion is transmitted to the nerve center and the resulting sensation is referred to the point of origin. If stimulation is applied to the same nerve along its course the resulting stimulation is referred to the origin of the nerve. When a limb is taken off if the divided end of the nerve is subjected to pressure the resulting sensations are referred to the limb as if intact, the preponderance of evidence being that in the case of an amputated limb feeling is still associated with the limb as a whole. In the case of a motor nerve the action is similar. When a voluntary stimulation arises in the brain it passes over the motor nerve and excites the muscle. If the nerve is cut along its path and stimulated

peripherally the same contraction takes place and it seems to be of the same character as the normal one. This indicates that when the nerve is stimulated it is thrown into activity along its entire length, the nerve being said to be polarized. (2) Impressions in connection with the sensory nerves may pass either from the inside out or from the outside in. This does not take place normally but it has been demonstrated that it is possible by cutting a sensory nerve and reversing its position so that the former peripheral end is united towards the center. By removing the skin from the tail of a rat and inserting it under the skin of the back grafting took place, after which the tail was cut at the base, continuing to be attached towards the center from the peripheral end. After six months complete sensibility was established in the reverse order, the sensory nerve which carried impulses from the point to the base thereafter carried the same impulses from the base to the point. This seems to be evidence of the possibility of impulses being transferred in either direction along the sensory nerve, indicating that there is not identity of action between the sensory and motor nerves.

SECTION IV. Contractility.

The most striking property of muscle is its contractility that is its corpuscles manifest their irritability by contracting or by the temporary alteration of form when stimulated, so that irritability and contractility are closely related. The response in the case of a muscle is a contraction or alteration of form, hence muscle is said to be contractile or to possess contractility because it evidences its possession of irritability by contraction when stimulated. Contractility is that property in virtue of which the protoplasmic cell changes its form when stimulated by external excitants or when under the influence of internal changes. This alteration in form does not necessarily involve changes in size. The alteration arises in connection with the fluid or the semi-fluid elements of the cell so that the cell changes its form to the spherical. In the amoeba we find that contraction involves the change of form, the pulling in of the tongue-like projections or feet so that the cell assumes the rounded shape. In the vorticella it involves the contraction of the outer parts in towards the inferior portions of the body. In these simple protoplasmic forms the contraction does not follow any special direction but in the higher forms of contractile tissue there is a differentiation of contraction which leads to the contraction and the subsequent relaxation taking a particular direction. By the stimulation of a muscle there is the liberation of energy involving chemical and electrical changes,this liberation of energy resulting in the readjustment of the muscle elements and producing the change in form. When the irritation is withdrawn this contraction relaxes and there is a more or less rapid return to the original form either on account of the elastic recoil or on account of some internal force that is inherent in the muscle. This restoration of normal form and position does not depend on external causes as a muscle when isolated from external influences, for example, by being placed on mercury, exhibits this relaxation when the stimulation ceases. This indicates that the contraction and following relaxation are independent processes and must both represent activity. When a muscle is stimulated it is seen to become shorter and thicker for a time, that is to contract and then relax or return to its original form. The same result will be observed if a single muscle fibre

is stimulated under the microscope, the contraction passing like a wave along the fibre from the point of stimulation. At the same time the light parts of the fibre are seen to become dark causing the dark and transverse striae to appear light. While both dark and light parts become shorter and thicker the change is most marked in the light parts of the fibre. Muscular contraction therefore is a change of form not of bulk as may be proved by causing the muscle to contract inside a vessel shaped like a specific gravity bottle and filled with water. If the contraction involved a diminution of volume the level of the water in the capillary neck would fall but this is not the case. Foster says that the muscle does slightly diminish in bulk during contraction. In the body probably muscles are always stimulated to contract by nervous impulses but any agent which will rouse up dormant irritability will act as a stimulus, for example, mechanical, chemical, thermal or electrical influences. To be effective a stimulus must have a definite duration a certain intensity and must act abruptly or suddenly.

Contractility is inherent in muscles. It is a property of the muscle fibres themselves and it exists and is quite capable of being manifested altogether apart from the nerves which are nearer the medium through which in the body nervous impulses reach the muscles and arouse activity. The truth of this may be demonstrated by stimulating a single muscle fibre freed from all nervous connection under the microscope when contraction will be observed to take place; or by putting a frog under the influence of curari which poisons the end plates of the nerves in the muscles. If in an animal so treated a stimulus is applied to a nerve passing to any muscle no contraction follows but if the stimulus is applied direct to the muscle contraction at once takes place. The instruments used in studying muscle contractions are the revolving cylinder, chronograph, myograph, frog muscle plate, in connection with the induction coil, keys, commutators, etc. We must distinguish between natural and artificial contraction of a muscle. If the gastrocnemius muscle of a frog is removed from the leg and made to contract it becomes a rounded mass about one third of its original length. In the body when living no such contraction takes place because the muscle is normally elongated and kept stretched by means of the opposing muscles and the muscle relations. Hence the contraction will depend upon the muscle length as well as upon the stimulus and the duration of the stimulation. In connection with the contraction McKendrick says there is a slight diminution of volume so that the change in specific gravity may be represented about one, representing about one-thousandth part of the volume of the muscle. The contraction takes place in the anisotropous part of the fibre representing the sarcous muscle element. Engelman says that the double refractive elements are enlarged and the single refraction elements contracted. Whether this takes place or not it would seem that the anisotropous part is shortened and broadened.

Phases of a Simple Muscle Contraction.—To study the phases of a single muscle contraction the muscle is placed on the muscle plate and its tendon is attached to the lever. The muscle or its nerve is brought into contact with the electrode and there is introduced into the circuit from the battery a signaling apparatus will indicate on a revolving cylinder the instant that the stimulus reaches the muscle and on its being moved by the shock the cylinder is made to rotate and a single electric shock is transmitted. The muscle shortens and after returns to its original form.

This moves the lever and a tracing, as it is called a muscle curve, is drawn on the smoked paper covering the cylinder. By means of this arrangement it is seen that the muscle curve produced by a single contraction is the result of a single momentary stimulus which consists of these phases, (1) the period between the reception of the stimulus and the beginning of the shortening during which there is no apparent change in the muscle. This lasts about one-hundredth part of a second and is called the period of latent stimulation or contraction; (2) The period of shortening during which the muscle shortens or strictly speaking contracts represented by the ascent of the curve; (3) The period of relaxation during which the muscle returns to its original length represented by the descent of the current. It occupies rather longer time than the second. The relaxation is the result of active changes in the muscle just like the contraction and not a mere passive recoil. By repeating the stimulus again and again as soon as one contraction is over a series of indentical curves may be obtained. After a time however the muscle becomes fatigued and then the curve does not rise so high the period of relaxation being prolonged. If the stimuli are sent to the muscle so rapidly that the second contraction begins before the first is completed and the third before the second contraction is finished, then the amounts of shortening resulting from the action of successive stimuli are added together and the muscle rushes into a state of tetanus, that is a state of extreme and persistent contraction which continues until fatigue comes on or the stimuli cease when it slowly relaxes. What appears to be a simple contraction is really in this case a number of contractions fused together, the result of numerous impressions that reach the muscle at the rate of about 19 per second. A contracting muscle therefore is in a state of vibration and like other vibrating bodies it produces sounds which can be heard by the stethoscope placed over a contracting muscle. When a muscle gives a single contraction the eye can not follow it and hence the only way of following the changes is to use the graphic method for tracing out the continuous alterations. Hence the kymograph with its blackened surface is used to represent the muscle curve, the muscle being connected with the mechanism that rises and falls when contraction and relaxation take place so that we are able to get a myogram. This apparatus is called the myograph, the writing part consisting of a light lever moving lightly on a delicate axis. the lever being connected with the muscle so as to represent on a magnified scale its movements. When the record has been made on the blackened paper it can be made permanent by dipping it into a thin solution of shellac in alcohol. The movement of the surface takes place by clock-work so that accurate time relations can be observed. In the myogram the curve represents the changes in form, the height of the curve representing the change in the length of the muscle, the shape of the curve depending on the rapidity of the revolving drum. From this it is necessary to know the rate of the revolution in order to understand the relations of the different parts of the curve to each other. This rate is registered by the chronograph which consists of several wire coils wound about soft metal cores and a small lever carrying anir on strip which is attached to the soft metal, when magnetization takes place by the passage of a current of electricity through the surrounding coils. As soon as the current ceases to flow the metal ceases to be magnetized and the lever is drawn off from the metal by a spring. By the use of this instrument very accurate calculations of time can be made, the break of the current

taking place when the magneto-electric tuning fork acts, the chronograph stylus tracing out the interruptions on the myogram. In this way we can mark out beneath the kymograph successive periods to very minute variations so that the curve changes and the time periods can be marked side by side for comparison. The chronoscope of Fitz is a convenient form of time piece as a substitute for the chronograph, the pendulum being almost frictionless and successive experiments may be conducted without any loss of time intervening.

Great variations are found in the muscle contractions so that no definite principle can be laid down as to the form of the muscle curve, the condition of the muscle and its stimulus determining the nature of the contraction. Take for example the gastrocnemius muscle of a frog, fixing the tendon to the myograph lever and bringing the electrode into contact with the nerve, by the rotation of the kymograph and the opening of the circuit an induction shock will be passed to the nerve producing muscle contraction. On the analysis of this curve there are found to be three unequal periods; (1) latent period. The period elapsing between the time the stimulus reaches the muscle and the moment when the muscle begins to alter its form is called the latent period, Helmholtz was the first to investigate the time relation of muscle in connection with latency. He concluded that for frog's muscle the average period of latency is one-hundredth part of a second, that the period of ascendency in the curve is about four-hundredths and the period of descending in the curve about five-hundredths of a second, the entire time occupied in the curve being about one-tenth of a second. Recent investigations have led to the conclusion that the latent period is not so long as Helmholtz thought. Tigerstedt after curarizing the muscle of a frog placed it on the myograph so arranged that at the moment when the muscle moved the current is broken, the break being recorded on the kymograph in connection with the electromagnetic chronograph. He found the latent period to be one 250th part of a second. This he did not regard as the true latent period because he believed that the muscle begins to respond even before the lapse of this very brief period During the brief period certain molecular changes take place in the muscle itself that prepare the muscle for contraction and during this period we find an electric change represented by the negative variation. In the human muscle the period of latent stimulation is shorter than in the frog's muscle. The length of the period of latency may be increased by heat or by the increase of the stimulus and it may be diminished by cold or fatigue. In the pale colored muscle the period is shorter than in the red muscle. If there is an interference with muscle metabolism either in the muscle substance or in the relation of muscle and nerve there is a lengthening of this period. For example, in paralysis agitans, locomotor ataxia as well as in muscular atrophy the periods increase; in the case of senile chorea the period becomes very short. (2) The second period is found that corresponds with the muscle contraction varying from .03 to .4 of a second. Contraction takes place more rapidly in a fresh muscle than in a fatigued muscle. The total contraction in the muscle represents the contraction taking place in the minute muscle fibres. As the distances that require to be traveled in connection with the contraction wave are very minute these undulations travel very rapidly and therefore the changes in the muscle take place very rapidly. It is claiming that the contraction begins even during the latent period, some claimed that there is really no latent period. In the passage of a muscle from rest to activi-

ty there is a change in the muscle condition, this change being detected by the use of the galvanometer. By the capillary electrometer it is found that a change in the electrical condition of the muscle can be found .0025 of a second after the application of the stimulus. If this is true and we take account of the difficulty in detecting the variation it may almost be said that the change in muscle begins as soon as the stimulus is applied, so that during the entire latent period there will be a change taking place in the muscle. This would imply the abolition of the latent period. There is undoubtedly a latent period at least for the muscle as a whole. A distinction has been drawn between the electrical latent period and the mechanical latent period, the former representing the period between the stimulus application and the first electrical change that can be detected, and the latter between the application of the stimulus and the first mechanical movement or alteration in the muscle form. At any rate it may be definitely concluded that the mechanical latent period is longer than the electrical. The latent period varies according as the muscle is stimulated directly or through the nerve, in the latter case the latent period is more appreciable in length because the time required for nerve conductivity is added to that necessary for muscle contraction. Hence the motor end plates are said to have a definitely appreciable latent period of stimulation distinct from the contraction period of the muscle. (3) The third period is that of relaxation, indicated on the myogram by the descending part of the curve. The length of the period will depend on the strength of the stimulus and the period occupied by the preceding contraction as well as on the condition of the muscle. Usually after the relaxation has taken place there are found a few contractions quite irregular which are spoken of as after contractions; these arise from the elastic action of the muscle and therefore become more appreciable if the muscle has been subjected to a strong contraction.

In comparing the different periods and characteristics of the contraction and relaxation it is important to get a number of curves side by side. This can be done easily by the use of the traveling stage invented by Marey, according to which the myograph is carried by the revolving screw driven by clock-work horizontally beside the revolving drum. In this way a shock can be sent into the muscle at each revolution of the cylinder. By the arrangement of a wire to the axle of the cylinder so that in connection with a cup of mercury each revolution of the cylinder will open and close the current passing through the primary induction coil so as to secure consecutive contraction at each successive contact. The period of muscular contraction is found to vary in different kinds of muscle, being very short in that of birds, a little longer in fishes and mammals and longest in the reptile. The amount of the muscle contraction is increased as the stimulus increases, first quickly and later more slowly, after which a maximum is attained when the contraction continues to be constant. The amplitude of the contraction is lessened by fatigue and in connection with cold or interference with the blood circulation, whereas it is increased in pathological conditions such as diabetes, jaundice and cerebral hemiplegia. Muscle contraction in the human muscle may be very rapid as is found in connection with the use of the laryngeal muscles in music. When contraction takes place in a muscle there is in addition to contraction the thickening of the muscle, the curve of thickening being almost the same as that of contraction. When a stimulus is brought to bear on one end of a muscle there is an indulation passed along the

muscle called the wave of contraction. This wave of contraction Marey has measured in regard to the time occupied in its transmission by the use of myographic pincers which grasp the muscle at certain points along the path of undulation. Each of these pincers is connected with a Marey tambour so that by transmitting the impulse a tracing can be secured of the effect. Marey pointed out that the two curves secured do not correspond, the difference between the maximal point of ascent in the two curves representing the rapidity of the wave which Marey found to be from 39 to 119 inches per second. In the cardiac muscle he found that the wave travels very slowly being only about .39 of an inch per second. In the human muscle it is estimated that the rapidity is about 390 to 420 inches per second. The wave of contraction may be retarded by fatigue or the increase of heat which tends to coagulate the muscle or by injection of sulpho-cyanide of potassium. If a wave of contraction is aroused in a single fibre or group of fibres it is confined to the single fibre or group of fibres and does not pass by radiation to contiguous fibres, so that muscle contraction takes place in the whole muscle only when simultaneous stimulation is aroused in the fibres as a whole. In connection with stimulation of muscle by nerve as each muscle fibre has its corresponding neural process and as the motor plate is associated with the central part of the fibre the contraction wave passes along the fibre length. The muscle contracts as a whole when the fibres receive their neural impulse all at once, so that the simultaneous action of the muscle fibres is necessary as the basis of muscle contraction and the origination and transmission of muscle contraction waves.

In an ordinary striated muscle we find a large number of muscle fibres grouped together into bundles all collected into muscular form in connection with connective tissue. In each fibre we find a minute elastic sheath forming the sarcolemma filled with the sarcous materials. In connection with the microscope the fibres are found to be striated with alternating light and dark bands corresponding with minute discs found possessing different degrees of transparency. The light bands are also found to be divided into two parts by a delicate mark side by side with which more delicately colored markings are found. The thin dark lines were formerly supposed to be formed in connection with delicate partitions dividing the muscle fibre into compartments. This view as we have seen has been found incorrect so that the fibres consist of a succession of parts closely packed together without any septa. In the muscle materials we find two substances, the double refracting or anisotropous and the single refracting or isotropous. The isotropous substance represents the sarcoplasm which is scattered through the muscle fibre and which contains within it the isotropous materials. In the striped muscle fibres we find not only the cross striae but also the longitudinal striae especially in connection with the dark bands. These longitudinal striae represent the anisotropous matters forming incomplete fibrils. The isotropous matter is semi-fluid, the anisotropous being arranged in the semi-fluid substance. During the contraction of this striated muscle the fibres are shortened and become thickened, the light and dark bands becoming shorter and thicker, the dark bands becoming larger and the light bands smaller. In the contracted portion the dark bands become lighter and the lighter parts become darker. Engelman believes that contraction takes place in connection with the anisotropous matter imbibing and absorbing some of the isotropous matter, this taking place in connection with

the setting free of heat resulting from the stimulation of the muscle. In this way the muscle contraction takes place in connection with the changes in the minute fibrillae and the changes in the muscle as a whole are dependent upon the changes in the minute fibres. These changes are rendered possible on account of the elasticity of the minute fibres in virtue of which the fluid part is capable of changing positions. Muscle elasticity is not very great but it is perfect, according to which the muscle when stretched becomes quickly restored to its normal size and form. In the use of the stimulation of electricity in connection with the muscle although the current passes almost instantaneously the contraction and the return to normal form again requires time. When an induction shock is sent into a nerve connected with the muscle there is a nervous impulse communicated to the nerve which travels along the nerve, reaches the muscle and produces an invisible effect during the brief latent period, then an effect which is manifested in the contraction of the muscle. These changes represent alterations in the living substance of the muscle and vary with the conditions of the living matter, being found only so long as the muscle is living. So much so is this the case that the three phases of the contraction may be altered independent of each other. Even when the same strength of shock is applied there may be difference in the contraction and the relaxation may also vary considerably.

In the contraction as we have seen the variation takes place in the minute fibres, the connective tissue between the fibres not being active, so that the muscle fibres which are connected to the tendon pull immediately in connection with the tendon and the muscle fibres not so connected with it through the connective tissue which is continuous with the tendon. In the muscle there is the nerve supply ramifying in connection with the connective tissue, dividing and branching in connection with the groups of fibres, each muscle fibre being connected with a neural process in a special terminal called the plate. As the neural plate is about the middle of the fibre, not at the ends of the muscle fibre, the neural impulse enters the muscle from the nerve about the middle of the muscle fibre the impulse travelling from this point towards the two ends. In connection with the skeletal muscles the fibres do not all begin at the muscle ending, so that as the neural processes are distributed among the fibres in such a way as to make the neural plate also distributed among the fibres at different points representing different distances from the muscle endings. In this way when the impulse passes through the nerve and enters the muscle, it enters at different points along the minute fibres the alterations originating at these different points so that the muscle contraction is greatly spread out over the muscle. This does not imply that all the muscle contractions must take place from that point of origin in connection with the nerve, because by poisoning the motor nerve with curari and applying the stimulation direct to the muscle at any point in the muscle fibre a contraction will follow. In the sartorius muscle of the frog we find parallel fibres running alongside each other, by poisoning the nerves so as to stop the neural action and applying the stimulus to one end of of the muscle the contraction begins at the point of stimulation and travels along the muscle, the contraction and the thickening taking place as the wave of contraction moves along the length of the muscle. This wave of contraction passes over each successive part of the muscle producing continuous shortening and thickening in each fibre, the sum of these representing the contraction of the muscle as a whole. Such a con-

traction wave travels too fast to be followed by the eye so that preparations like osmic acid are used to represent the local contractions, so that from thess we may gather the changes taking place in the whole muscle. Whatever else takes place the contraction represents a transference of molecules from location to location, the method of this alteration being as yet indistinctly understood. What is certain is that certain changes take place representing alterations in form but not in bulk in connection with single muscle fibres, the sum total of these alterations representing the changes taking place in the muscle as a whole.

Muscle Changes in Contraction and the Conditions Affecting the Contraction.—Contractility may be different not only in different muscles but in different kinds of muscle found in the same animals. The same thing we saw to be true of irritability. Irritability represents an independent muscular property but it is found that contractility and irritability are existing usually to the same extent in each separate muscle. Where irritability is hard to excite it is found that the contractions resulting represent slow and long continued contractions, whereas if irritability is easily aroused there is a rapid contraction followed by a quick relaxation. The contractility manifests different degrees of activity. This is found for example in different animals, the striped muscle of the frog representing a duration of contraction of .1 of a second, that of a turtle about one second. It is found that even in the same animal or the same kind of animal different forms of contractile power are exhibited. Cash has made the following analysis of striped muscle of the frog as to the duration of contraction, the triceps femoris muscle .104, semi-membranosus .108, gastrocnemius .120, abdominal rectus .170, hypoglossal muscle .205 of a second. This has an interesting connection with the functional use of the different muscles. In the omohyoid muscle in the turtle which is used to pull back the head quickly under the shell the contraction takes place very quickly; in the petoralis muscle the contraction takes place very slowly although it represents great strength in connection with the locomotive movements of the body and the support of the body weight. The unstriped muscle which is characterized by slow movements is found to be associated with the intestinal walls and the blood vessel walls in which it is necessary to have slower actions and in which the muscles remain for a longer period in the contracted condition. In the case of the cardiac muscle great strength is required to overcome strong resistance and to pump out the blood, so that we find the mixed muscle capable of strong but slower movement. In the case of the mammals we find that nearly all the muscles of the body can move more or less quickly the modification depending on the use of the muscles and the amount of work done in connection with the muscle use. Hence the vocal cords are capable of very quick vibrations in their contractions, while the skeletal muscles are moved at different rates depending on the amount of work done in connection with the movements of the skeleton. In the case of the limbs and arms the muscles are capable of very quick movements, so that the economy of the muscular contraction depends on the purpose that is to be served by the contraction in the different forms of body movements. Here we find a distinction between the red and pale muscle, the former being found where the contractions are extended and the latter where the contractions are shorter and more vigorous. In some cases we find a combination of the pale and red muscle the contraction being originated in connection with the pale muscle fibres while endurance is given to the

contraction of the muscle in connection with the red fibres. Thus the function of the body or part of the body in which the muscle fibres are found determines the nature of the contraction as we find it in connection with the fibres themselves, the use regulating the activity and the character of the activity. In studying the character of the contraction of muscle several instruments are used to determine the changes taking place. In all of these artificial expedients are resorted to in order to test the character of muscle activity.

This is evident from the fact that by the application of a weight or of stretching applied to the muscle there is a variation in the resulting contraction. Hence if a muscle is loaded with a considerable weight there is a difference in the contraction as compared with the muscle when free and simply tense. If the muscle is made to contract while it is thus weighted the muscle is said to be loaded, but if the weight is so arranged that it does not bear on the muscle until the contraction begins the weight is said to be an after-load. If the weight loading the muscle is equal throughout the contraction it is said to be isotonic, but if the contraction has to take place against a force that is increasing like a spring it is said to be isometric. Each of these conditions involves an alteration in the contraction of the muscle and represents an important modification of the contractility. Hence we may find that the latent period is extended, or that the periods of contraction and relaxation are modified. The modifying effect of the rapidity of the stimulation upon the contraction is important. If the same excitant be applied to the muscle for several times and under the same conditions, the contractions resulting ought to be the same if the muscle continues the same in its internal condition. The internal condition of the muscle is subject to variation and this variation takes place whenever the muscle is excited and a resulting contraction follows, so that a decided effect is left upon the muscle after each contraction. This change in the internal condition is temporary. When the muscle katabolism is increased there is an accompanying and corresponding increase in the anabolism and provided the contractions do not follow each other in too rapid succession the changes taking place during contraction are compensated for by the changes taking place during rest. When the blood freely circulates through a muscle in connection with contraction or relaxation there is a normal recuperative influence taking place which overcomes the contraction changes so that at each stimulation the contraction will be about the same. This is well illustrated in normal conditions by the heart which continues to beat without a stop during a lifetime the resting periods following each contraction giving the heart sufficient recuperation to enable it to continue steadily. It has been found that by stimulating the skeletal muscles it is possible to accumulate the contractions by the thousand without any signs of over exertion, but in the end if the contractions are kept up steadily there is a lessening of the contractile force. This will not be the case if sufficient time is allowed for restoration to active functionality so that the normal condition of the muscles depends upon the normal alternation of activity and rest.

The extent of the contraction of a muscle represented by the height of the muscle curve is usually taken as a mark of muscle activity and capacity for activity. By stimulating the muscle very often it can be seen plainly that the endurance and capacity for activity are represented by the limit of the contractions. At first the effect of stimulation is to increase irritability but after this first effect is over the irritability is les-

sened. It is found that the action of a muscle within certain limits increases the muscular activity. This was first discovered in connection with the frog cardiac muscle. It was found that by applying stimulation successively to the cardiac muscle a series of contractions followed increasing in force so that each succeeding contraction represented a greater amount of activity than the one just preceding, representing a gradually ascending series of curves. The same was found later in connection with the skeletal muscles and with all forms of bioplasm. It has been found that by graduating the strength of the stimulation so that each stimuli represented the same force that there is a temporary decrease in the resulting contraction for five or six contractions followed by a steady increase, the first contractions being called the preliminary and the later the ascending contractions. This seems to indicate that the first effect of stimulation is to diminish irritability, the katabolism being too great to be compensated for by the anabolism, each contraction representing a diminution of force. As soon however as the anabolic reaction sets in the the anabolism increases as the katabolism increases and we find the gradually increasing force of the contractions of the muscles. This however can not be carried out indefinitely for a period is reached when fatigue is induced and there is a descent in the contraction scale. This fall in the scale represents fatigue the katabolism once more gaining and the anabolism declining gradually, representing the descending curve of exhaustion. It is found that this descending curve is not steady in its decline but that the decline is greater immediately after the maximal point has been reached while towards the end there is a more constant fall. These variations represent the normal changes taking place in muscle. Hence it is well known that a muscle can not be raised to a maximum of activity without a preparatory period of stimulation during which the muscle is in training for the maximal effort. This is in line with the experience of athletes, whether in running, walking, rowing or pulling, the muscles requiring to be lead up gradually to a supreme effort. These preliminary preparations have a double object, (a) to prepare the muscles for better and more sustained action; and (b) to secure better coordination of muscular effort especially under the guidance and coordinating influence of the nervous mechanism. The muscular stimulation is necessary to stimulate the nerve cells and as the nerve cells can only be adjusted to action by repeated stimulation on the part of the muscles this is a necessary part of the training both of the muscles and the nerves that control them. The capacity for activity on the part of the muscle therefore varies and at any moment in the history of muscular activity there is a specific capacity for activity on the part of the muscle. This is explained by some on the basis of an automatic mechanism within the muscle itself that regulates the supply of materials to the cells of the muscle and therefore controls the setting free of energy. The nature of this automatic mechanism is unknown and its influence on the muscle is not clear. It seems clear that the mechanism has control and can regulate the output of energy and if so it must also regulate the income of materials, supplying the necessary energy. Here there is in the muscular economy a balancing arrangement in virtue of which the katabolic and anabolic changes are regulated, stimulation of either kind acting as an excitant to the other. In the case of muscular activity it is found that this arranging mechanism has an important influence on the period of latency and also on the expense of the muscular contraction. When muscular

contractions follow each other rapidly there is an influence exerted upon the form which the resulting contractions assume. There is a stimulating effect therefore arising from the contraction itself as well as from the rate of the contraction as compared with the rate of the stimuli.

As the stimuli follow each other with greater rapidity greater changes are noticeable in the resulting contractions leading up to that peculiar kind of contraction known as tetanus. In the case of the normal muscle when it is first stimulated it returns to its orginal position almost as quickly as it contracts. If on the other hand it is quickly stimulated the power of relaxing is gradually lessened in force so that there is produced a tendency to remain in the contractile condition. This tendency is found even before the coming on of exhaustion and is increased gradually as the exhaustion becomes more pronounced. If a frog's muscle is stimulated about once every one and one-half seconds the periods of contraction will increase and this will have the effect of retarding the restoration of the muscle to its normal condition during the intervals between the contraction periods, because one contraction will not have become relaxed before another stimulation takes place. Hence there will be a change in the power of relaxation resulting in the existence of two contraction periods, the one going forward continuously and the other marking an intermittent action arising from successive stimulations. This represents an imperfect tetanus in which there is continuity in the one contraction and intermittent contraction. In the perfect tetanus there is only the continuous contraction, a series of contractions running into each other so that there are no independent contractions, the muscle presenting an unchanging curve. As the muscle relaxation becomes slower the condition of shortening also becomes slower representing a condition called contracture which increases as the force and rate of the stimulation increase. The production of this condition depends on the muscle condition at the time of the stimulation. The stimulations must be frequent and rapidly applied in order to produce this condition. It is not necessary however that this results from an exhausted condition of the muscle as the contracture is diminished when fatigue increases. Thus there is a gradual development of the ascending or descending curve of contraction accompanied by a gradual rise in the base curve indicating the gradual completion of the contracture until out of the imperfect tetanus there is developed perfect tetanus.

Great variation may be found in the formation of this tetanic curve depending on the nature of the stimuli and the rate of application of the stimulation. It is certain, however, that when muscle is tetanized the contraction as represented in the curve will be much greater than if resulting from a single contraction. In the case of a fresh muscle a series of contractions produces an increase in irritability, resulting in an increase in the contractions, but this when continued reaches a limit which cannot account for the great length of the tetanic contraction. Helmholtz stimulated a muscle with two induction shocks of equal force varying the intervening period between the stimulations. He found that by giving the second shock during the period of latency of the first contraction there is the same result as if but one stimulation is applied; if on the other hand the second stimulation takes place during the contraction period resulting from the first stimulation, the contraction resulting from the second stimulation is super-added to the contraction stage of the first

stimulation at the stage at which the action is produced, so that the first and second contractions are fused together to form one great contraction. This has not been confirmed by more recent experiments. Kries finds that the existence of the first contraction quickens the second contraction and Frey has discovered that the Helmholtz principle of summation effects applies only to the case of muscles that are loaded. In the case of unloaded muscles he found that the effect of summing the contractions represents the maximum when the second contraction begins during the period of the contraction resulting from the first stimulation If the second contraction begins during the relxcation of the first contraction it may rather retard than assist the second contraction. It seems generally admitted that if the second contraction begins during the direct period of contraction resulttng from the first stimulation there is a summation of effects. This may be explained by the fact that the excited condition induced by the first stimulation is not exhausted and to this is added the excitation resulting from the second stimulation, producing the greater contraction by the setting free of a greater amount of energy.

Yet this does not sufficiently explain the great contraction found in connection with tetanus. It is no doubt true that according to Helmholtz the first contraction does not afford a certain basis on which the increase of a second contraction takes place and so on. It has been found that when a muscle has to lift a weight through a small space the contraction will be greater in the muscle, so that if the muscle is stimulated at regular intervals and if the weight support is elevated between each succeeeding contraction the contraction may be as great as it is found in the case of tetanus. This can be secured when the summation is rendered impossible by keeping the stimuli apart so as to prevent summation. It is found that if a muscle unsupported is stimulated quickly very much the same contractions are found as in the case of a supported muscle. When stimulated for a definite time there is found a change in the muscle condition which seems to indicate the presence of an internal force aiding the external stimulation, resulting in the increase of the contraction. This new internal element is spoken of as the internal support afforded to the muscle. If a muscle is subjected to a series of induction shocks, moderate in strength with gradually increasing force, important changes are noticed in connection with the tetanus. At the opening of the experiment there is a single contraction followed by a single relaxation. These are followed by the gradually ascending contractions until a point is reached when the maximum is attained followed by a gradually descending contraction curve. These facts seem to indicate that tetanus results from a number of circumstances associated with the muscle and the stimuli. The most important condition however of the tetanic condition is that the stimulations must take place at brief intervals of time, so that as each contraction follows the other there must be an influence imparted to each succeeding contraction, this influence being felt in connection with increased excitability producing the gradually ascending scale of contractions; added to this we find the summation of the effects so that the result of each succeeding stimulation is imparted to the contraction and in this way additional support is furnished to the contracting muscle in the act of contracting. As we said, the chief factor in the tetanizing of the muscle is the repetition of the stimulation at brief intervals of time The number of stimuli necessary to produce tetanus depends on the condition of the muscle regulating the individual contractions and, therefore, de-

termining the result when all the effects are summed up. The effect is also determined by the length of the individual contractions and the contractile condition induced in the whole muscle by the individual contractions. Perfect tetanus can be produced in an unfatigued muscle when the period intervening between the stimulations is shorter than would produce in the muscle the greatest contraction from a single stimulation. When the unstriped muscles are stimulated by lengthened stimuli they pass into a a peculiar tetanic condition produced by the application of interrupted closures at intervals of several seconds. The periods necessary have been estimated, the red striped muscle of the rabbit tetanizing at ten contractions per second, the pale striped muscle at 25 or 30 per second. In the case of the muscles of birds and smaller insects from 100 to 250 contractions per second are necessary. It is found that tetanus can not be produced in the cardiac muscle, the rapidity ot stimulation simply producing the characteristic rhythmic contractions peculiar to the heart action.

In regard to the rapidity of stimulation resulting in the production of tetanus there is undoubtedly a limit to the tetanic condition produced in such a way. Striped muscles and nerves are capable of receiving stimuli at very rapid rates. It is claimed by some that when the rate of excitation becomes so great that it can be indirectly excited through the nerves supplying the muscle tetanus will not follow. The high rate which fails to give a tetanic result can not be determined because in each muscle there are individual conditions that determine the refusal to be tetanized. The amount of contraction found in a muscle when tetanized depends largely on the character and condition of the muscle. The pale striped muscle while capable of more frequent single contractions does not shew the same height of tetanus as the red striped muscle, possibly because there is greater endurance in the latter. Associated with the red striped muscle we find a greater abundance of sarcoplasm and for this reason this form of muscle has been called the tetanic muscle, because it is very ready to respond in tetanic contractions. In the case of the human muscles it is found that by becoming tetanized they manifest a much greater tension when tetanized against an increasing force than when they respond to a single stimulation. By analyzing the conditions found associated with the different muscles it is possible to determine the value of the different muscle contractions in the body. But this has not been attempted so far in the human subject. The tetanus is determined by the intensity of the stimulation; if the stimulation is strong then the individual contractions are greater and this intensifies the tetanic condition. This is of importance physiologically because all the normal muscle contractions in the body are tetanic and these are carefully graduated in intensity under the influence of the will. Hence there must be a very careful coordination of impulses between the muscles and nerves to produce the delicately adjusted muscle contractions that depend on the activity of the nervous system.

We have seen already that by the use of a continuous current of electricity there may be produced a continued contraction. By using a very strong current the closing of the current produces a contraction that represents the closing tetanus and the opening of the current a contraction called the opening tetanus. These contractions as found in connection with the human muscle are called sometimes galvanotone. The opening tetanus originates at the positive and the closing tetanus at the

negative electrodes, from which points the contraction is diffused to the rest of the muscle, unless in abnormal circumstances when it remains localized at the point of production. It is questioned by some whether these represent a true tetanic condition, because they do not arise as other tetani from the application of a number of stimuli in frequent succession. This is claimed on the ground that in the closing tetanus there are irregular contractions as well as the regular continuous contraction, these intermittent contractions arising probably from chemical changes taking place in the muscle in connection with stimulation. After the muscle is contracted it assumes its normal length, otherwise if it remains partially contracted it is said to be in a condition of contracture. We find this generally in muscles subject to strong stimulation and hence fatigued or in muscles that are very acid or poisoned by veratrin. Mosso found by the use of the ergograph that this existed in human muscle. It is found at the opening of a series of contractions and is lessened by the increase of fatigue. He considers it a kind of fatigue resulting from overstimulation and exhibited by the muscle at the beginning of its action. In the case of the application of two successive stimuli, if each stimulus is sufficient to give a maximum contraction the result will vary according to the time intervening between the stimulations. If the stimuli do not give a maximum contraction then the effects of both stimuli are united and we have a summation of contractions, the greatest effect being secured when the second stimulus is applied during or shortly after the opening of the first contraction period. If such stimuli, each able to produce contraction, follow each other so as to prevent the elongation period in the relaxation of the contraction the muscle continues in a vibratory tetanic condition. It represents a discontinuous condition of the muscle aroused by such a summation of contractions. The fatigued muscle is thrown more easily into tetanus because fewer stimuli produce this condition of the muscle in which the contractions are fused.

In voluntary contractions of the human muscle there is an imperfect tetanus produced by the passage of 8 to 10 successive nerve stimuli per second. The frequency of the stimulation necessary to produce the tetanus will depend on the rapidity with which muscle relaxation takes place so that if the rapidity is lessened the frequency of stimulation may also be lessened. It is this that causes fatigued muscle to become tetanized more readily by fewer stimuli per second than fresh muscle and a muscle that is cooled than a muscle that is warmed. There is found a limit below which a muscle can not be perfectly tetanized and as we saw before there is also an upper limit to tetanization. In regard to the upper limit much investigation has taken place without any generally accepted results, because it is found that the number of stimulations per second can not account for this higher limit, account requiring to be taken of the intensity of the separate stimuli, the muscle temperature and the condition of the muscle itself. Bernstein found that tetanus could not be produced when the rate of stimulation was 250 per second, while in the case of strong stimuli at a rate of 1,700 per second tetanus could be produced. Stirling and Kronecker have found tetanus when stimuli were at the rate of 24,000 per second. One difficulty suggested is that each electrical shock may not represent a stimulus so that the various experiments in connection with the electrical shock may not be a perfect means of testing it. During the contraction in a tetanized muscle energy is liberated that may be converted to work. While the contraction is preserved no

work is done, although there is a liberation of energy shown in the increase of CO_2 given off and the amount of lactic acid developed. This indicates that tetanus exhausts a muscle more readily than a series of single contractions. Tetanus may be produced by a very slight external stimulus, for example, when the peripheral nerves are injured a slight movement of clothing, a slight draught of air or even a sensation produced in connection with noise may be sufficient to throw the muscular system into a tetanic spasm. This takes place reflexly in connection with the spinal cord. In connection with this tetanic condition it is to be observed that the muscular contraction takes place suddenly, that the tetanus lasts a considerable time and that the relaxation of the muscle takes place very slowly.

Three different phases have been distinguished in connection with the contractions leading up to tetanus. (1) When a second stimulation acts after the close of the contraction resulting from the first stimulation there is produced a second contraction and so on with successive stimuli and contractions until the muscle becomes exhausted. (2) When the second stimulus acts during the period of latency of the first contraction the contraction is just the same as from a single stimulus. (3) When the second stimulus acts during the period of contraction of the first stimulus the contraction corresponding with the second is added to that of the first. If other stimuli quickly follow the effects are added together so that a permanent condition is produced representing the fusion of all the contractions. This represents the true tetanus which in its genesis is a fusion of individual contractions. The interest of these contractions centers in the fact that many of the muscle movements of the human body are tetanic in character; hence the flexing of the arm produces tetanus in connection with some of the muscles. Kronecker has proved this by the use of two needles one of which he placed in the muscle and another in the muscle tendon, connecting the two by a telephone arrangement. By tetanizing the muscle he produced the characteristic sounds arising from the vibratory motion of the muscle. All the skeletal muscle actions consist of this fusion of single contractions into tetanus. In the case of human muscle the lowest limit will represent the number of impulses communicated to the muscles by the nerves, as the tone produced in connection with a contracting muscle represents the first over-tone of a primary note resulting from about 19 vibrations per second. Probably the normal stimulus arises in connection with a succession of stimuli producing muscular power corresponding with the rate of rapidity of the impulses as vibrations are found to take place during the activity of muscle contraction. Some physiologists deny the identity of the tetanus produced in connection with stimuli applied to motor nerves and the voluntary muscle contraction. Complete tetanus is secured by the application of stimuli to a nerve about 37 times per second. It is claimed that when the stimuli are applied to motor nerves through the cerebral centers not more than 8 or 10 contractions take place in the muscle per second, so that Schaefer concludes there is no relation between the artificial tetanus and the normal muscle contractions. He concludes that the average rate of muscle contractions is about 10 per second. This is difficult to reconcile with the experiments of Helmholtz and Marey in which very much more rapid muscle contractions have been found. Indeed the rapidity of contraction in the voluntary muscles depends on the will. Hence by the active operation of the will very skillful and rapid movements of the mus-

cles may take place, every movement depending on a nervous impulse. Hence Helmholtz says that for an unloaded muscle the average number of vibrations is about 10 per second, the contractions being discontinuous: while in the case of muscle subjected to strong contractions he estimates that 19.5 vibrations per second represent the average.

In connection with the normal muscles and nerves they are incapable of bearing artificial stimulation for an indefinite time so that they readily become exhausted. The same thing is true of the muscles subject to muscle nerve stimulation. When a muscle is exhausted a tetanic condition is much more easily induced the contractile power being lessened. As the muscles become fatigued the contraction of the muscles becomes more easy as the nerve force becomes exhausted. Here the question arises, is the beat of the heart a long drawn twitching or a brief tetanus? If the nerve in a nerve muscle preparation is placed across the beating heart the cardiac muscle gives a single contraction at the beginning of each beat and sometimes at the close of the beat. This is taken to indicate that the contractile movements of the heart are single and not multiple. It also indicates that associated with and accompanying each contraction of the heart there is a double phase in the variation. This double variation indicates the negative character of activity in connection with uninjured tissue. The meaning of this double variation is that there is not simultaneous action throughout the entire cardiac muscle but that it takes time to pass from one part to another. In the case of a frog's heart it has been found that during the first phase the base is negative to the apex and during the second phase the apex is negative to the base. In connection with the electrometer it is found that in the case of a human heart there is a double movement both of these movements being in the same direction. In opposition to this view it is claimed that the heart sounds indicate the tetanic character of a cardiac contraction. It was originally claimed that muscle sounds originated only in connection with tetanus. But it has been found that the sounds exist even where there is a single contraction, the sound varying either short or long according to the shortness or length of the contraction. Hence in the case of the double variation in the heart each ventricular contraction represents a single spasm, the only difference in the cardiac muscle as compared with the ordinary striped muscle being in the length of the contraction. Hence the cardiac contractions are not tetanic, the muscle being incapable of tetanus.

We have seen that a muscle in connection with a nerve when stimulated can do a certain amount of work. This amount of work depends on a number of conditions and circumstances associated with the condition of the muscles and nerves and especially with their nutrition and irritability. A muscle may be contracted under two different circumstances, (a) the muscle may be free to contract, in other words the contraction may be isotonic, no obstacle being presented to prevent the one end of the muscle from approaching nearer to the other; (b) the muscle may be hindered from contracting, that is the contraction may be isometric, the contraction being only of the nature of a strain without any variation in the muscle length. In general the contraction in the former case is governed by the stimulus so that if the stimulus is feeble the contraction will be correspondingly feeble and if strong it will give a stronger contraction. It is presumed that when a muscle is stimulated through the nervous system all the nervous fibres are stimulated and therefore all the

muscle fibres are similarly stimulated to contraction. In this case the strength of the contraction depends on the strength of the stimulus. This is true of the single induction shocks so that as the strength of the stimulus is increase d the muscular contraction is increased within the limits of maximum and minimum stimulation and contraction. In the case of tetanus we have seen that with the increase in the frequency of the stimuli the individual contractions are lessened until we get a curve in which the individual element is lost so that the fused contraction is very much greater than the individual contractions. The frequency of the repetition of the individual stimuli varies in different animals and in different kinds of muscle in the production of this complete tetanus. In the case of isometaic contractions it is found that the contraction does not vary directly with the weight. It does not depend upon the amount of the weight but rather on the increase of the weight which seems within certain limits to increase the contraction. The resistance met with in a weighted muscle increases the contraction. This is in line with the fact that when muscle fibres are stretched there is an increased muscle metabolism favoring the increased contraction. There is a limit to the increase of this resistance, beyond which no contraction takes place. As the fibres of the muscle are not so long as the length of the wave contraction, as the fibre increases in length the contraction produced in the fibre will be increased by the same wave of contraction. Hence where a muscle consists of a series of parallel fibres the contraction will depend upon the fibre lengths and the amount of work to be done by the muscle will be in direct proportion to the number of fibres in the muscle. Hence if two muscles are of equal length the muscle with the greater number of fibres will be able to do the most work provided the fibres are of equal cross sectional area; and in the case of two muscles equal in cross sectional fibre area the muscle that is longer will do the greatest work.

In connection with the human muscle one method used is to measure the increase in thickness during the contraction by the use of leverage or the Marey tambour. Another method is to measure the rapidity of the contraction wave. By stimulating a long muscle at one end the contraction wave is propagated, the molecular disturbance thus originated being transmitted along the muscle in virtue of its conductivity the mean rate of the contraction wave being in the frog 117 to 157 inches per second, while in the voluntary human muscles the rate is about 390 to 470 inches per second. In the unstriped muscle the contraction wave lasts a longer time, for example, in the ureters and intestines the wave travels slowly from end to end. The contraction in this case is not tetanic in nature but tonic being a single prolonged contraction. When artificially stimulated the contraction passes from fibre to fibre the contraction being lessened in rapidity by the contents found within the vessel walls which act as a force of resistance. The contraction may be modified under the influence of cold, fatigue or the approach of death, lessening the velocity of the waves. No modification of velocity takes place in connection with the load in connection with the muscle or the strength of the stimulus. In the living skeletal muscle the contraction does not pass from fibre to fibre, the impulses passing from the nerve to the fibres in connection with the nerve fibres.

The normal muscle contractions are of the nature of tetani. The most limited muscle contraction is too long to be a single contraction. As the muscles can be stimulated to continuous contractions only by a

succession of stimuli it seems impossible to explain these contractions on any other theory. This implies that the nerveimpulses are of a rhythmic character so that the contraction arising in the muscle in connection with the motor nerve is not a single continuous contraction but a discontinuous long contraction. When the voluntary muscles contract there is a muscle sound indicating the vibration of the fibres. By the use of delicate mechanisms these delicate vibrations have been found although no such vibrations seem to be visible. By exposing the surface of a muscle and keeping it moist there is noticed an optical phenomenon especially the flickering of the reflected light indicating the muscle vibrations. When the muscle becomes fatigued it passes into a tremulous condition, the tremors being manifested as pathological sound. A number of experiments have been made in the attempt to discover the rate of muscle stimulation. In connection with the use of an induced current it is found that following the excitation there is a muscle vibration corresponding with the rate of stimulation. In the case of a muscle in tetanus there is manifest a continuous contraction accompanied by a number of sounds corresponding with the rate of stimulation. Hence in the normal muscle the number of vibrations would indicate the number of impulses given to the muscle by the nerve. During the voluntary contraction of a muscle it gives out a hollow dull sound corresponding with the vibration of about 35 to 40 per second. By placing the stethoscope over the contracting biceps muscle the sound may be heard; or even without the stethoscope the vibration of the masseter muscles may be heard if the ears are stopped. Helmholtz by the use of small rods placed on the contracting muscle found that only those rods vibrating at the rate of 20 per second began to oscillate when the muscle contracted. Hence he concludes that the vibrations produce not a tone but the octave or the overtone, the resonance value of the ear being from 36 to 40 vibrations per second, indicating that at least about 20 vibrations would represent the vibrating rate of the muscle contractions.

More recent experiments seem to point to a much slower rate of from 8 to ten per second, the rate depending on the muscle in connection with which the experiment is made. Horsley and Schaefer in connection with stimulations of the brain and spinal cord as well as the motor nerve trunks, and Loven in connection with the tetanus produced by strychnine found that the vibrations recorded were from seven to twelve per second and that the rate of vibration differs from the rate of excitation. Loven found that the muscle sound become louder on the application of the weakest current that could produce tetanus. The resulting sound corresponded with the number of vibrations in the next octave below. When the current becomes stronger the muscle sound vanishes although it is found to reappear when the number of vibrations are the same as in the case of the interrupter of the induction by the use of a stronger current. By the application of induction shocks to the nerve the sound is lessened although it possesses the same number of vibrations as the interrupter. If the induction shocks are rapid Bernstein found that tones were produced by as many as a thousand vibrations per second. It has been found that oscillations increase as the muscle becomes fatigued. It is difficult to reconcile this contraction rate with the view that muscular action normally represents a tetanic condition. It is found that muscle can be continuously contracted voluntarily while at the same time developing brief quick contractions. This has been explained by some on the basis of a double in-

nervation of the muscle, while others explain it on the basis of a double muscle substance, the one responding slowly the other more rapidly. If these explanations are correct there must be a double contraction series taking place in the muscle, although the evidence seems to point in the direction of the tetanic character of the muscle contraction. It is characteristic in any case of the muscle contraction that when the muscle contracts if it is kept in a condition of tension in connection with the resistance force it will give a semi-musical tone. Helmholtz thinks that these muscle vibrations produce the resonance tone of the ear. We do not hear the low tone as the number of vibrations per second is too few but we hear the first overtone in which the number of vibrations is donble that of the oscillations. In the case of a single muscle twitching a short sharp sound may be produced. Hence the stimulation of the muscle by a single induction shock causes a sound of a sharp character called the contraction sound, coinciding with the period of the negative variation. This indicates that the muscle sound simply does not enable us to say whether the contractions of the human muscle are tetanic in character or not. There is an indication in the fact that the muscle vibrations are constant in connection with the various nerve stimuli, that these vibrations represent rhythmical changes so that in all voluntary muscles when contracting there is an oscillation that is constant. This gives evidence of the discontinuous character of the contraction. Secondary tetanus however does not result from voluntary contraction. This of itself does not disprove the existence of a normal tetanus because chemical stimuli do not produce secondary tetanus.

This does not settle the question however whether the nervous impulse is a continuous or a discontinuous current. It would seem according to some that some of the shorter contractions are not tetanic, the time allowed for such a contraction being too short to admit of anything more than a single contraction. It is found that when the excitant is of the same strength there is a difference between the irritation taking place directly or taking place through a nerve. Rosenthal has experimented in this connection by allowing the nerve of a muscle to rest on a muscle curarized while an electrical shock is applied so as to excite the first nerve and the muscle on which it rests to the same extent, with the result that the latter muscle contracts less than the former. This is in line with the principle that when the stimulation is voluntary there is a much stronger response than when stimulation is artificial. This is carried even further for when a muscle is fatigued it will respond to voluntary stimulation, whereas it has ceased to give any response to artificial stimulation. Hence the normal stimulation of a muscle is more effective than the artificial stimulation. Mosso finds that there is very little difference between the muscles of the human subject and that these differ only slightly from other warm blooded muscles and even cold blooded muscles. A muscle is more readily fatigued by artificial stimulation but the voluntary impulses passed through the nervous system do produce ultimately fatigue. In these cases however it is a question whether the fatigue exists in the muscle or in the nervous system, particularly in connection with the nerve cells. This is indicated by the fact that the nerve cells are exhausted before the muscles.

In this fact we have an explanation of another fact that a muscle when exhausted by electrical stimulation can still be contracted by the will. There is certainly considerable advantage to the body organism in the fact that the muscles should have greater endurance against fatigue than

the nerve cells because this protects the muscles from over-exertion. The word fatigue physiologically indicates a condition of lessened capacity for work induced in a muscle in connection with prolonged activity. Accompanying this fatigue in the human muscles there is a feeling of weariness. A muscle that is fatigued very readily recovers its contractility in the living subject. Waller regards fatigue resulting from over stimulation as analogous to the loss of excitability on the death or degeneration of a muscle. Fatigue is produced probably as we have seen partially by the accumulation of certain waste products in the tissue, these products being formed in the muscle during activity; and partly from the lack of nutriment to sustain the muscle in connection with further exertions. In order to get the same amount of activity from a muscle that is fatigued the stimulation requires to be very much stronger. A muscle that is fatigued cant no do a very large amount of work so that there is a diminution of its absolute working force. The more rapidly the contractions follow each other the greater will be the condition of exhaustion induced in the muscle. A muscle that is fatigued contracts slowly the latent period being also longer. It is claimed by some that a fatigued muscle has greater extensibility. By loading a muscle with a weight which it cannot lift when it contracts there is a greater fatigue induced in the muscle than if the muscle could lift the load. In connection with a series of contractions it is found that with the increase of the number of contractions the contractions become longer and the latent is also longer. By ligaturing the artery and stimulating the motor nerve it is found that from 100 to 250 contractions in two or three minutes produces complete muscular fatigue, although the muscle still retain thes power to respond to direct stimulation by contraction. The muscle is fatigued very much more rapidly than the nerve although the nerve may be exhausted more rapidly. The fatigue seems to begin in connection with the end plates. If the nerve conductivity is affected by fatigue before irritability. Waller states that after death nerve irritability continues even after its action on the muscle has ceased, the muscle still continuing subject to direct stimulation. In is possible that this is due to the direct effect which fatigue produces on the motor terminal plates.

In the case of a frog poisoned with veratrin it is found that by stimulating the muscle electrically the elongation following contraction gradually disappears although it reappears after a period of rest. By the use of strychnine the same action will be found the strychnine affecting the spinal cord as the veratrin affects the muscle. Recovery from the fatigued condition is assisted by permitting a constant electric current to pass through the muscle or by injecting fresh blood into the vessels or by the use of small doses of veratrin. After a muscle has come completely fatigued it is found that the muscle fibres become granular and show signs of degeneration. The cross striae remain visible so long as the sarcoplasm is not decomposed but as soon as it decomposes the cross striation disappears. This indicates that important degenerative changes take place in connection with the muscle when it is fatigued. Heat when brought to bear upon the muscle within definite limits produces an increase of muscle irritability and conductivity, also assisting the changes that take place in connection with the liberation of energy. By raising the temperature the latent period of stimulation is lessened, the period of contraction is increased while at the same time both contraction and relaxation take place in a shorter time. This

of course is limited by the temperature of 45 degrees in the case of a frog and 51 degrees in the case of human muscle which represents the stage after which thermal rigor begins accompanied by the loss of vitality. Cold has the opposite effect to that of heat so that by cooling the muscle there is a prolongation of the periods of latency, contraction and relaxation. The results of heat in connection with the muscle are not simple but complex. In the case of striped muscle during the time that it is cooled if stimulated from time to time by single shocks it is found that there is not a gradual decrease in the contractions. A maximum of contractions is attained about 30 degrees C, from 30 to 20 degrees there is a decrease, from 20 degrees to zero there is an increase and below zero there is another decrease in the contraction until at freezing point there is no muscular contraction at all.

The influence of chemicals upon the muscle is not only to change the irritability and the contractility of the muscle but also to change the character of contraction. The most interesting chemical from this standpoint is veratrin. If a small quanity of veratrin, one per cent solution, is injected subcutaneously in the brainless frog the reflex movements in connection with the spinal cord are completely altered, the contractions resulting from stimulation being of the nature of a spasm, the relaxation being diminished. The action of veratrin is upon the muscle itself as is evident from the fact that by poisoning the muscle with veratrin and placing it in connection with the myograph the contraction resulting from a single shock will indicate a normal contraction and an abnormally prolonged relaxation. Sometimes between the contraction and relaxation there is a check indicating that the relaxation has begun and been cut short possibly by a second contraction to be followed by the relaxation. This condition of continued contraction represents a contracture which may pass away by the exercise of the muscle, indicating that it is a chemical effect upon the muscle, not of the nature of fatigue. Fick says that more heat is produced during this contracture than during the normal resting condition and this seems to indicate that it represents an active condition of contraction. The deviation between the contraction and the relaxation has been taken to indicate the fact that there are two kinds of muscle, the one contracting slower than the other, so that as the first contraction is produced more quickly and the second more slowly the relaxation is intercepted by the variation between the two contractions. By the use of carbonate of sodium the same interrupted relaxation or double contraction of the muscles may be found. A similar double contraction it is claimed is found associated with the muscles of frogs in connection with increased irritability arising from frequent irritation. The same phenomena are found associated with barium salts and also with calcium, the prolongation of the relaxation being characteristic without any diminution of the contraction. Potassium salts cause the muscle to degenerate so that as the degeneration is developed stimulation results in lengthened contractions and relaxations. This however is different fron the effect produced by the other chemicals because it is associated with a quick diminution in muscle contraction.

According to the law of the conservation of energy applied in the case of the living body when a muscle contracts a certain amount of energy is liberated, the energy not being lost but transferred to some form of activity. When energy is liberated it passes into some of the vital phenomonea. In connection with muscular contraction certain chemical changes

take place these changes being associated with the transformation of potential into kinetic energy. In connection with the muscles we find that the transfer of this energy takes place into mechanical, thermal and electrical phenomena. The greatest part of the energy set free is transformed to heat and liberated in the forms of motion and heat. There are varying proportions of these two forms of energy depending on the nature and conditions of the muscle and also the kind of work done by the muscle. Fick claims that in case the muscle acts against strong resistance 25 percent of the energy liberated may be transformed into mechanical work while in the case of a small resistance not more than five to ten percent of the liberated energy becomes mechanical work. Thus a large part of the energy developed in connection with a contracting muscle becomes heat. According to Engelmann in the muscle contraction the anisotropous elements absorb part of the isotropous fluid materials chiefly in connection with the evolution of heat. If this is so then the first transformation taking place is into heat part of this being utilized as heat and part of it as mechanical energy in connection with which a reconversion of heat takes place.

The method of calculating the amount of mechanical energy set free by a muscle is by estimating the amount of work it does. This means that an amount of energy is imparted to external objects as in lifting a weight. The amount of mechanical work done being estimated by multiplying the weight lifted by the height to which it is lifted. The capacity for work on the part of the muscle depends on certain conditions, (1) in connection with the muscle. Different kinds of muscle can do different degrees of work, the muscles of the cold blooded animals being less capable of work than those of the warm blooded animals. The human muscles can do more work than the muscles of a frog the ratio being about four to one. The capacity to do mechanical work also depends on the constitution of the special muscle, the muscular power being represented by the amount of weight which when the muscle begins to contract prevents the contraction without interfering with the muscle by way of stretching it. In other words its muscular capacity is represented by the force which counteracts exactly the power of contractility supposing that the muscle is stimulated to the maximum of contraction. This amount of muscle force will therefore depend on the proportion of the contractile substance in connection with the muscle and also the arrangement of the muscle fibres. The strength of the muscle depends on the way in which the muscle fibres are arranged, being estimated in reference to the cubic centimeter. Thus the muscle force of a frog's muscle is about six and one-half pounds per c. c. and the human muscle about three or four times that of the frog, namel y20 to 26 lbs. per c. c. Insects from theis size can do an immense amount of work hence an insect can pull 65 times its body weight compared with a horse which can pull only about twice its weight. While the absolute muscular force is thus estimated we must remember that certain limitations exist to lessen the muscular force; anything that tends to diminish irritability, for example, lack of nutrition or exhaustion will diminish the capacty for work by lessening the amount of energy set free, while anything that increases irritability will at the same time tend to increase the working force. The most favorable condition is that of resistance as the resistance to the muscular force stimulates the liberation of energy to overcome the force of resistance.

(2) Conditions in reference to the stimulation. We have seen that with

the increase of stimulus there is an increased amount of energy set free within definite limits. In addition to this a number of quickly repeated stimuli are more valuable than a single stimulus, because in this way irritability is heightened and the tetanic condition is induced so that the muscle is brought into a condition capable of doing a larger amount of work. When a muscle is free and unweighted no work is done; if a muscle when it contracts strongly does not shorten because of the tension then no work is done; and if a muscle simply lifts a weight and lowers it during relaxation without changing the environment as the effect of activity no work is done. In these cases mechanical work is meant because in all these cases there is physiologically work done resulting in the production of exhaustion. It is true that energy is developed in connection with the muscle but this energy assumes the form of heat. (3) The weight represents an important condition in connection with the muscle contraction because it determines the amount of shortening that takes place. In the case of a muscle which supports a load at its normal resting length and is then stimulated to a number of maximal contractions, the load being increased at each contraction, the contraction in the muscle is gradually diminished but there is no direct relation between the amount of contraction and the increase in the load. The contraction is diminished more rapidly at the beginning while it is lessened later. Tension has also an important bearing on muscle contraction. If a muscle is connected with a spring and stimulated to isometric contraction and while the contraction takes place if the muscle is freed from the load represented in the spring, the contraction of the muscle will be found to be greater than if the contraction were excited without any tension. This is seen best in connection with the cardiac muscles. By increasing the blood pressure in the heart under experiment the rate as well as the force of the cardiac contraction is increased, the increased pressure representing the condition of tension. In the case of a muscle by increasing gradually the weight the contraction isgradually diminished while the amount of work is temporarily increased. After a time a limit will be reached and the amount of work will decrease until a point will be reached when the muscle can just support the work. This will represent the absolute muscle capacity. The first result of contraction in a muscle is the tension of the muscle suddenly and the greater the load in connection with the muscle the greater will be the elongation. In this way at the opening of the contraction there is an expenditure of part of the energy without any effect. The way in which the weight is applied has an important bearing on the work to be done by the muscle. By applying the weight before the beginning of the contraction so that the muscle is in a condition of tension when the stimulation is applied there is an effect produced in connection with the increased metabolism that interferes with the work to be done. Hence it is better to after weight the muscle that is to prevent the weight being laid on the muscle till the contraction begins.

(4) The muscle individuality has an important bearing on its capacity for work. Not only do the muscles of different animals vary in the rate of contraction and work that can be accomplished, but even in the same animal such differences exist. In the case of the rabbit the contraction of the pale muscle like the adductor magnus is much faster than that of the red like the semi-tendinosus. This does not always depend on the histological structure of the muscle, for example the gastrocnemius muscle of the frog contracts four or five times faster than the hyo-

glossal. In the human subject the muscles of the leg contract much slower than those of the arm. Here we have an individual coefficient of contraction in the individual muscles. The muscles therefore represent perfect mechanisms in the use of the materials of which they consist and in the fact that by continued use they increase in capacity for work. In the case of the maximal stimulation producing the greatest muscular contraction there is an increase of work within definite limits. By increasing the weight so that the height to which it is lifted is lessened then the amount of work done is diminished.

Certain principles have been laid down in connection with muscle work, (a) the greater the cross section fibre area of a muscle the greater the amount of work it can do; (b) the longer the muscle fibres the greater the height it can lift a weight; (c) the greatest weight can be lifted by a muscle when it commences to contract, while during the progres of contraction the weight that can be lifted is lessened so that when the contraction is maximal the smallest load can be lifted; (d) the absolute muscle force represents the load which can be lifted by the muscle just when the muscle is subject to a maximal stimulation without any muscle elongation; (e) In the tetanic condition of a muscle if the load is continued in suspension no work is done by the muscle although there is physiological work done. In connection with the tetanic condition there is an increased metabolism representing the change of potential energy into heat. In connection with muscle stimulation by moderate stimuli it is found in connection with work that either the load varies while the stimulus is weak so that the same principle would apply as in the case of maximal stimulation; or the load may not vary while there is variation in the stimulus. In the latter case the principle of maximal stimulation does not apply but the amount of work done increases directly with the increase of the stimulus. During muscular activity there is an increased blood supply so that the amount of blood circulating through the muscle is increased the vaso-dilator fibres being excited along with the motor fibres because these lie in the same path.

The coefficient value of certain individual muscles or groups of muscles may be determined by the dynamometer. This is used often to determine the capacity of muscles. By grasping the instrument an index is preserved of the force, Quetelet estimating the pressure of the two hands in the male at 154 lbs., the pulling force 308 lbs; in the case of the female the pressure force is 104 and the pulling force 208 lbs. Hence he estimates that a man can carry a load equal to twice his body weight, while a female can carry a load equal to her body weight. In considering the work done by an individual we must consider not only the work done at a definite period but at successive periods, hence it is said that the average daily work of an individual working eight hours per day is eleven kilogram-meters per second representing daily about 300,000 Kg-ms. Muscular work may be lessened or increased by the use of certain chemicals, for example, mercury, digitalis, helebore have the effect of paralyzing muscle work production; while veratrin, glycogen, muscarin have the effect of increasing the amount of work that can be done.

(5) In the normal body the muscle tension has a good deal to do with the amount of work done. Every elastic body has its normal position so that after being stretched it tends to regain this normal position. In the living body the muscles are slightly stretched on account of the muscle relations to bone, tendon etc. This stretching is very important be

cause if it did not exist the body movements would not be possible. This tension depends on the action of different muscle groups especially the antagonistic muscles. The elasticity of an active muscle is less than that of a passive muscle, that is it may be stretched more if active than if passive under the influence of a weight. On account of this tension when contraction takes place no time is lost and no energy expended in getting the muscle into a contractile condition; at the same time this muscle tension lessens the shock of the contraction so that it does not take place suddenly but gradually, preventing the tearing of the muscle attachments. The muscle energy passes from the body through this elastic medium to the external body so that on account of elasticity the amount of work done is considerably increased. In connection with the work done by a muscle there are therefore various forms of functioning, (a) that of the stimulus. In general the eontraction increases with the increase of stimulus, first quickly and then more slowly until the attainment of a maximum after which on account of fatigue the contraction decreases. This of itself cannot determine the work because the work is the product of the contraction and the weight lifted; (b) that of the weight. If the stimulus is preserved the same, while the load lifted is gradually increased it is found that as the weight increases the contraction increases to a point from which by the increase of weight there is a decrease of contraction: (c) that of time in connection with the stimuli. By varying the time between the stimuli, while preserving the load and the stimulus the same, it is found that if a certain time is allowed to intervene between stimuli the amount of work done can be preserved; while if the time is lessened the muscle becomes fatigued. Hence the work done depends on the weight, the length of the muscle and the cross section area of the muscle, or since the last two represent the weight of the muscle in activity it depends on the weight of the load and the weight of the muscle.

By the use of Mosso's ergograph estimates may be made of the work done in Kg.-ms. The half supinated arm has an attachment to a horizontal bar, around the middle finger being attached a ring with a cord passing over a pulley the cord bearing a weight. The hand is kept in its position by the insertion of the second and fourth fingers into tubes. The raising of the weight by the middle finger is registered so that the movements can be accurately measured and compared. Here we come to a subject of considerable importance, namely the scientific application of exercise in connection with physiological culture. Exercise certainly furnishes a therapeutic agent and to Osteopathy exercise from the standpoint of the patient and physician represents one of the most important therrpeutic means. To adjust the amount of muscle exercise to the condition of the patient is certainly a problem of great difficulty on account of the lack of symmetry in the muscular system of invalids. It is claimed and with great truth that in all adults on account of peculiar habits of life some of the muscle groups have been allowed to fall into idleness. It is this that gives rise to the concave chest, the rounded shoulders, the prominent abdomen, the curved condition of the spine and the abnormal position of the head. In the case of chronic diseased condition it is almost impossible to find a case in which some of these abnormalities are not found. Attempts have been made to form a scientific ideal on the basis of anthropometry but these have failed because individual structural variations are so frequent that the standard must be in quality rather than in the quantity of the muscle. One reason for the imperfection in the diagnosis of these cases is that no

accurate dynamometers were available in connection with which all the different groups of muscles could be tested. This is practically obviated by the invention of the Kellogg dynamometer by means of which every group of muscles can be tested so as to determine the relative strength of the muscle. It can be applied in connection with the upper and lower extremities, the muscles of the trunk, of the neck and the thorax. The principle on which it works is to apply the resistance of the dynamometer at the peripheral end of the bone that is in connection with the group of muscles tested so as to test the muscles while securing the isolation of the muscles from all other muscles. By the use of the percentage principle in connection with the graphic method the capacity of different muscles and groups of muscles can be obtained so that the amount of exercise can be graduated in proportion to the capacity of each muscle, so as to secure the symmetrical development of the muscles of the body. Here we have the basis of the true principle of physioioglcal culture. By regarding 300,000 foot-lbs. as the normal exercise required for an individual whose strength capacity is 10,000 lbs. we have the basis for establishing a definite relation between the capacity for work and the amount of work done. The total capacity for work in an average individual is 1,800,000 and by dividing this by 10,000 we get 180 representing the principle that for every lb. of capacity the muscles can do 180 foot lbs of work. The exercise is estimated at about one-sixth of work value, so that in a person normally developed every muscle must perform an amount of work equal to 30 times its capacity to lift a weight, this capacity being determined in connection with the dynamometer. In connection with this instrument it is possible to diagnose paralysis in connection with the motor system, as it selects the muscles that are affected indicating the point where to look for a central lesion, the paralytic condition representing the symptoms of the central lesion. By its use the nerve fibres and nerve centers can also be tested so as to gain an exact account of the dynamic value of the motor system. It can also be made use of to indicate the progress towards recovery in paralytic conditions.

One important use of this instrument is to compare the muscular condition of the male and female. The tabulated results indicate from the comparison of 200 healthy men and 200 healthy women the great relative strength of the male as compared with the female, the various groups of muscles in the female as compared with the male representing a strength varying from .39 to .65 of that of the male, representing an average of about half the strength of the groups of the muscles in the male. Some interesting results have been found in comparing the strength of various groups of muscles, for example, the posterior muscles of the neck represent about twice the strength of the anterior muscles in the male and female; the arm flexors in the male are about half and in the female about one-third the strength of the hand flexors; the latissimus dorsi and the muscles active in inspiration in the upper thorax are about equal in the male, while in the female the same equality exists between the latissimus dorsi, the pectorales and the retractors of the shoulders; the inspiratory strength of the thorax and abdomen are equal in the female while in the male the inspiratory force of the thorax is greater, the respiratory force of the female being about half that of the male. This indicates the falsity of the supposed theory of waist contraction so as to give to the female greater thoracic respiratory strength.

This is found that the normal female is very much inferior in

strength to the normal male, for example the abductor muscles of the thigh which represent the strongest female muscles represent only about seventy percent of the same muscle force in the male; while the latissimus dorsi, foot flexors and extensors, anterior and lateral trunk muscles, anterior neck muscles, and expiratory muscles have fifty percent of the force of tne same muscles in the male; the other muscles like the forearm supinators and pronators, the arm flexors and extensors have less than fifty percent of the strength of the same male muscles. The leg muscles are relatively stronger than the arm muscles in the female, possibly because the bones of the legs are shorter and the upper thigh is wider in the female giving to the muscles a more perfect leverage and a more solid foundation. The greater thigh development is dueto the larger development of the muscles and not simply to a larger proportion of adipose tissue. In the case of the inspiratory strength the difference between male and female is much greater than that of the expiratory, this being largely due to the modes of dressing, the form of clothing in the female retarding inspiration and assisting expiration. Another prominent difference between the male and the female is to be found in the much greater strength of the muscles of the back in the male, the weakness of these muscles being also due in part to the mode of dressing in the female which prevents thefree useof these muscles. This explains one of the constant facts in medical experience that females complain of tiredness in the back, partly due to the undeveloped condition of the muscles and the inability freely to use the muscles of this part of the body. In the female we also find that the pectoral muscles are much weaker than in the male, this having an important bearing on the weaker female inspiration. The strength of an average woman compared with her height is about 57 percent of the average male, whereas, in comparison with her weight the strength is about 70 percent of the average man. This principle is found both in the male and female, that the weight is increased with the cube of the height while the muscle force is increased as the square of the height, Here we find that the taller person has not the same advantage as a shorter person.

In an average man of symmetrical development the muscles on the two sides of the body should be equal but ordinarily the right is stronger than the left on account of the undue proportion of training and exercise. Some of the muscles on the left side are stronger than those on the right, for example the flexors and extensors and adductors of the thigh. This is explained by the fact, as Dr. Kellogg claims, that while right-handedness is the normal, left-leggedness represents the tendency to the normal in the lower extremities. This however is hardly borne out by observation. In the female the left side is stronger than the right at three points, these being different from the male, namely, the retractors of the shoulders, the extensors of the leg and the flexors of the foot. This is explained by the fact that in the female less bilateral symmetry is found in development, so that in the male the ratio of strength in the right and left sides is about 100 to 99, while in the female it is 100 to 98. By comparing talland short men it is found that at almost every point the shorter individual is at a disadvantage. The total force value of a short person compared with a longer person is about 90 to 100. There are some points however at which the shorter person has the advantage, for example, in the lateral and posterior neck muscles, in the deltoid and laternal muscles of the trunk. The difference between the height of the short and long is largely found in the difference in the length of the legs. The short per-

son has longer arms proportionately to height than the tall person, so that it is natural to expect the strength of the arms is greater than that of the legs in shorter persons. In the muscles of the trunk and the neck the advantage to the short person arises from the fact that there is a better leverage for the muscles. By comparing tall and short women short women are found to be at a disadvantage as compared with tall women in the total strength, the ratio being 92 to 100. In the case of the pectoral muscles, the muscles of inspiration and the posterior muscles of the trunk the shorter women have the advantage of the taller. The greater strength of the trunk muscles and of the inspiratory muscles is due to the same fact as we found in connection with short men. In comparing men and women of equal height there is very little variation between the male and the female. Many other interesting results might be traced out but these are sufficient to indicate the variations found among the sexes, the difference being due perhaps largely to training and use because hardly two individuals that can be examined have been exactly subject to the same conditions in life.

Muscle Tonicity.—While awake the cells of the central nervous system are subjected to a continuous series of feeble shocks in connection with the neural impulses from the sensory parts of the body. Even brain activity especially in connection with psychic conditions of emotional or intellectual activity produce an increase in the neural impulses that are sent to the spinal cord resulting in heightened irritability and greater excitation in connection with motor activity. If at any period during the walking hours the sensory impulses are considered as these enter the brain from all over the body it will be found that a vast number of such sensations of light, heat, sound, pressure, are stimulating the central nervous system and thereby influencing the activity of the nerve cells. The result of this continued sensory stimulation is to arouse a continued motor stimulation to the muscles producing in the muscles a continuous slightly contracted condition called muscular tone. There is a change during sleep because a certain amount of relaxation takes place which diminishes the number of motor impulses affecting the muscles. During the period of mental activity there is an increased tonicity due to the number of stimuli aroused in the brain and sent to motor channels. This muscle tonicity is due to chemical action in connection with the production of energy, this energy assuming the form of heat. It is claimed by some that when the muscles are subjected to nervous stimulation there is a heat generation independent of the contraction of the muscles. Hence it is claimed that there is a feeble but continuous chemical activity which produces a chemical tone of the muscles. There is no doubt that chemical tonicity is preserved by means of the minute stimulations arising in connection with the spinal cord; for if the cord is divided there is less O used up by the muscles and less CO_2 waste is given off. This implies that there must be a special set of nerves which are normally engaged in giving chemical tonicity to the muscles by the production of certain changes under the influence of the nerve stimuli so that there is an independent liberation of heat, altogether independent of the changes that take place in connection with muscle contraction. These as we have seen represent the thermal nerves both fibres and cells. By muscular tonicity then is meant that slightly contracted state in which some of the muscles, namely the muscle fibres of the arteries, and possibly all the muscles are maintained during life. It appears to depend on the connection of the muscles with the

nervous system. In the living being the muscles are more or less stretched between their attachments, hence they are said to be in a state of normal tension or tonicity. Various questions have arisen in regard to muscle tonicity, one of these being whether muscular tone is under the influence of the nervous system. Brondgeest divided the spinal cord of a frog below the medulla and then divided the nerves of the leg on one side; on fixing the frog firmly on a board he found the muscles of the leg on the side of the operation loose and the leg longer than the other. He concluded that the spinal cord furnished the muscle with permanent innervation. Heidenhain stretched a muscle by weights and he found that it does not elongate after section of the nerve supplying it. The probability is that both the innervation and the blood circulation have an equal influence on muscular tonicity by affecting the nutrition of the tissue.

SECTION V. Conductivity.

Conductivity represents the principle of bioplasm in virtue of which there is excited a condition of activity that is transmitted from one part of the substance to another. In the case of the amœba the irritation of the main body of the substance is transmitted through the body to the pseudo-pods. In the vorticella if the margin of the bell is stimulated very lightly the cilia cease to move and the contractile action of the substance pulls it into a more rounded shape, the same fibres also contracting and removing the body away from the stimulation. In both of these cases the commotion originated at a point in the bioplasm must have been communicated throughout the substance passing through the different forms of protoplasmic matter. This principle of conductivity seems to be inherent in the protoplasm as it is found in vegetable forms of life as well as animal. The substance of the protoplasm in the cell as it encompasses the nucleus consists of a semi-fluid granular substance in the midst of which we find minute fibrillae, sometimes arranged in parallel cords and in other cases irregularly arranged in a net-work. Whether the principle of conductivity belongs to the fibrillae or to interstitial substance or to both is not known It seems probable that the conductivity belongs to the protoplasm as a whole consisting of fibrillary and interstitial matters. The process of conduction varies very considerably in different forms of protoplasm, so that the rapidity depends on the form of the protoplasm and even within the same cell the different parts possess different degrees of conductivity. This is true not only of the primitive forms of protoplasm such as the infusoria, protozoa etc., but even in the striped and unstriped muscle. In the striped muscle the sarco-plasmic substance seems to have a much slower power of conduction than the fibrillary portion. In the unstriped muscle conductivity takes place very slowly and uniformly, representing it is supposed a more primitive form of structure with a lesser degree of differentiation. This differentiation is most complete in the nerve for the fibrillary axis cylinder of the nerve is capable of very rapid conduction.

In order to the possession of this conductivity it is essential that the bioplasmic substance maintain its integrity. If there is any break in the continuity of a nerve or muscle then the conductivity is interrupted. By cutting a nerve irritability and conductivity are preserved for some time in the severed parts but the relation between the severed parts is cut so that no communication can pass from the one to the other.

Some claim that a neural impulse is analogous to an electrical current. The analogy breaks down however for if we cut a nerve and bring the two ends together conductivity is lost, whereas if the cut ends of a wire are joined conductivity is restored. If the nerve is seriously injured without being divided there is no conductivity because of an interference with the necessary physical and chemical changes on which conductivity is based. What is true of the nerve is also probably true of all bioplasm so that any interference with bioplasmic continuity prevents the conductivity of impulses. This represents an important physiological principle because were it not that such continuity is necessary there would be great complication in connection with the impulses in passing through the body as so many impulses are passing in all directions at the same time. That this is so is found in the fact that where bioplasm seems to be very homogeneons all the different parts of the substance bear definite relations to each other and to the functions discharged by each, so that different impulses are capable of following their own direction without interfering with other impulses. At the same time the minute variation of particles is so complete, that it is possible in the event of very slight changes in the physical and chemical processes to change entirely the rate of impulses as well as their course so as to serve the purposes of physiological function. This is evident in connection with the effect of degeneration and regeneration upon the conductivity as well as the irritability of the nerve. As we have seen the fibre of the nerve depends entirely on its relation to the nerve cell so that any interference with that relation interferes with the activity of the neural process. If any portion of the nerve fibre is injured its power of conductivity is impaired or lost and if any part of the nerve fibre is cut off from its connection with the central cell then its nutrition is cut off resulting in death. After three or four days both irritability and conductivity are lost and the nerve fibre degenerates. There results a dissolution of the axis cylinder accompanied by a disintegration of the medullary sheath or white substance of Schwann, the dissolved and disintegrated matter being absorbed. This process of absorption goes on for about 14 days.

There may however be a regeneration of the degenerated nerve fibres and this takes place in an important manner respecting irritability conductivity. During the process of degeneration the dissolution of the axis cylinder and the medullary sheath takes place with the aid ot the nuclei lying close to the neurilemma so that a large number of these nuclei are found in connection with the process of proliferation. In this proliferation process there is formed a new protoplasm which accumulates in connection with the old sheath forming a continuous thread of protoplasm. Around this new protoplasmic portion there is developed a new sheath so that a new nerve fibre is formed. This newly formed fibre in the peripheral part of the nerve is united with the central part in connection with the tissue developed at the end of the central part in the healing process. In this way there is formed a temporary fibre which is united with the central part of the nerve that remained intact. This newly formed embryonic fibre is found to possess conductivity and to be capable of irritability although as yet it it has not developed either the axis cylinder or the sheath. It is irritable by mechanical stimulation before it responds to electrical stimuli. It is found that conductivity is restored before irritability appearing after about 21 days. In this way it is found that the sensations are restored before the capacity of performing voluntary movements is restored.

This does not depend on an essential difference between the sensory and motor fibres but rather on the fact that longer time is required to establish motor connection with the muscles. This temporary nerve fibre gradually gives place to the normally developed nerve fibres consisting of the axis cylinder and sheath. This takes place when the old axis cylinder of the central part becomes elongated, growing down into the peripheral part. In the development of the axis cylinder there is a restoration of the normal functions of the nerve although this does not take place for several months. In the case of the muscles the same thing is true. When the life of a muscle is lost or impaired the power of conductivity is impaired or lost. Muscle that is completely deprived of nourishment by ligature of the blood vessels, by removal from the body or by cessation of the circulation which occurs in the case of general death passes after an interval into the death condition known as rigor-mortis. Short of this the muscle may be killed within the body. If the middle part of a muscle fibre is killed by compression, heat or chemical action the death of the bioplasm interferes with the active conduction of impulses from the ends of the muscles. The interference continues until regeneration takes place. The muscular corpuscles themselves seem to lose the power of reproduction for if the muscle is cut across, the ends become united again not by muscular but by fibrous tissue. Only when the union takes place is conductivity restored, hence both in muscle and nerve the condition of conductivity is the continuity of the nerve and muscle tissue. This principle of continuity is the basis of the insulation of impulses so as to prevent diffusion and the loss of the power of impulses to serve their physiological purpose.

(a) In the case of the nerves the fibres run parallel to each other in nerve trunks. These fibres are separated from each other by the neurilemma. In the medullated nerves there is in addition the medullary substance or sheath, so that continuity is preserved only in the case of the distinct and separated nerve fibres. In this sense the nerve tissue is not continuous but simply the nerve fibre. This renders possible conductivity in the many fibres that are afferent and efferent as these are bound up in the same nerve trunk. If a sensory nerve is stimulated the impulse is transmitted to the spinal cord where it arouses to activity the spinal cells, these cells sending out impulses to the motor fibres which in turn transmit the impulses to the muscles. The sensory and motor fibres that perform this reflex run parallel to each other along the same trunk without any diffusion taking place from sensory to motor or vice versa. This holds true of the peripheral nervous system and possibly it also holds true of the central nervous system. This it is claimed forms the basis of the localization of sensations and forms the ground on which is built up the co-ordination of impulses representing co-ordinated activities. How this insulation takes place in the central system is a matter of dispute but possibly this is one of the important neural functions discharged by the neuroglia in insulating one tract from another. The various nerve ganglia and their processes are embedded in a mass of connective non-nervous tissue. According to some recent physiologists a distinction is to be drawn between the connective tissue proper and the neuroglia, Henle claiming that neuroglia differs from connective tissue in its chemical purposes. Ramification of the nerve fibres is rare in connection with the peripheral nerves. The ramification of the nerve trunks consists of bundles of fibres that maintain their integrity. When the

nerves reach and enter a peripheral organ the axis cylinder may be divided into a number of branches. In connection with the muscle there is a division and subdivision of the nerve fibres into minute processes. In connection with the spinal cord when the nerve fibres enter the cord they are divided into collateral branches. In what way this ramification takes place is not known, whether the axis cylinder fibrillae send out branches or whether a separation takes place, part of the fibres entering the branch and the remainder continuing in the main part is not known. Although the irritation does not pass from one fibre to another the fibres being insulated probably the excitation involves all the different processes of a single fibre.

(b) In the case of the muscles each of the muscle fibres in the skeletal muscles represents an independent part of the muscle. There is no continuity of these independent fibres on account of the sarcolemma and these fibres are separated from one another so that there is no radiation in connection with conductivity. To each of these fibres there is a nerve process so that normally the fibre is stimulated through an independent process. In cell life and in some cases in the muscles we find a surrounding sheath in connection with which we find protoplasmic substance uniting the cells together. In this case the connecting protoplasm acts the part of a conducting medium. It is claimed that there are exceptions to the rule of the absence of continuity as the basis of conductivity. In the striated muscle of the heart we find a different kind of muscle. It consists of cells of a quadrangular nature without any sarcolemma these cells being united laterally by means of processes and also at the broader parts of the cell. According to Engelmann conductivity takes place from cell to cell and not in connection with the nerves, impulses being transmitted freely in all directions. This he claims because he found that the impulses were transmitted in all directions without any nerve forming the basis of such transmission. Recently some physiologists have found in the cardiac muscle of the frog a free anastomosis of nerve fibres throughout the entire heart. This furnishes the basis of free communications between the different parts of the cardiac muscle, although Englemann claims that it is purely regulatory and not of value in conduction. It is claimed that in some of the unstriated muscle tissues there is conductivity by contiguity as this is found in some of the cells of the medusæ. In addition to this it is found that among ciliated cells there is an activity among the different cells without any direct connection either muscular or nervous. In these cells there is no membrane covering over the substance so that when activity is aroused in the one, free communication takes place simply by contiguity or through the interstitial substance. It seems therefore that the continuity of the bioplasm is the basis normally of conductivity while there are cases in which direct contact or an intervening substance may form the medium of conductivity. In any case where there is found a covering of sarcolemma this is sufficient to insulate one fibre or cell from another.

In connection with the spinal cord it is found that the fibres entering the cord do not terminate derectly in the neural cells but end in certain terminal organs quite close to the cells. This same form of termination is associated with all nerve cells which are subject to stimulation by nerve fibres. It is questioned by some whether these terminals represent special stimulating organs or whether they simply act as media forming a part of the nerve cell, or representing a neural process. It has

been claimed that these terminals represent real end organs because the cell can be stimulated through them although the end organs can not be stimulated through the cell. This seems to be probable because of the anology of the terminal plates in connection with the muscle fibre for these terminal plates are not really a part of the muscle but simply in contact with it. The muscle can be excited through the neural end organ although the organ can not be stimulated by the muscle. There is almost nothing known of the physiological function of these terminal processes in connection with the central nervous system. It is known that considerable time is taken in the passage of impulses through the central nervous system, the time being longer than that required in connection with the nerves; it would seem that longer time is required as the number of the cells is increased. It is claimed that this time is occupied in connection with these terminal processes in preparation for the stimulation of the cells. It is a well known fact that the motor terminal plates require more time for the passage of a stimulus than is required for the transmission of the stimulus through a nerve fibre. Hence it is found that a response is delayed if it passes through the nerve plate, part of the time being occupied in the nerve fibre and a longer portion of the time in the end plate. Bernstein calculates that .0032 of a second is occupied in the passage of an impulse through the terminal organ. This seems to indicate the fact that ~~that~~ the terminal organ is not a pure nerve, for example, the period of latency in connection with the end plate is long; in addition to this it is known that when a nerve is treated with curari the poison takes effect on the end plate and it is well known that the terminal organ loses its irritability more rapidly than either the muscle or nerve when it is subjected to malnutrition. When we find bioplasm continuous we have the basis of conductivity. In addition to this when the bioplasm is excited it would seem to possess the power of conducting in all directions although it is claimed that conductivity is not possible to the same extent in all directions.

Accompanying the transmission of the impulse are changes in form and for this reason it is easy to follow the process of conduction. The commotion travels through the bioplasm very quickly so that it is difficult to follow it out with precision. When a muscle fibre is subjected to stimulation in connection with its nerve fibre there is produced a change which is conducted along the fibre in both directions. In the artificial stimulation of a muscle fibre the stimulation passes along the fibre in one direction arousing within the fibre a continuous contraction. When the nerves are stimulated there cannot be seen any changes taking place so that it is not possible to determine exactly how the conductivity takes place. While the nerve is in its normal position in the body its stimulation can only be estimated from the stimulation which it imparts to the muscle. Attempts have been made to unite the central portion of a sensory nerve fibre with the peripheral portion of a motor fibre allowing the crossed fibres to regenerate and testing whether the stimulation of the sensory fibre produced movements in connection with the motor fibre. We have seen already that Bert united the extremity of a rat's tail with the tissues high up on the back, finding as a result that complete regeneration took place and after the regeneration by cutting off the tail at its root sensations were still preserved in the tail. This however does not give any evidence of the principle of conductivity, because as we have said when a nerve is cut it degenerates peripherally and its irritability and conductivity are re-

stored by the growth of a new axis cylinder out from the central end so that the sensory part of the nerve creates a new path along which impulses may travel by conduction.

Another method has been followed by some experimenters to prove that nerve tissue is capable of conductivity in both directions. It was observed that while the nerve fibres seldom ramify on their pathway to an organ as soon as they enter the organ they very freely ramify. This is the form in which we find the minute nerve processes in connection with the muscle and Kuhne claims that by stimulating one of these minute branches the stimulation passes upward to the general nerve fibres and then passes downward along the other branches. He took the sartorius muscle of a frog, dividing the one end of it in two and found that by stimulating one of these divided ends the other end contracted. We know that there is no cross radiation in connection with the striped muscle so that Kuhne concludes the conduction must have taken place upward and then downward. DuBois Raymond experimented on the different fibres as found in the roots of the spinal cord. He found upon stimulating the nerve that a certain electrical variation was found, this variation passing along the fibre at the same rapidity and in the same path as the neural impulse. He found that this electrical variation represented the direction of the impulse. By stimulating the centripetal fibres in the posterior roots of the spinal cord and of the sciatic nerve he found that there existed a negative variation, as the current produced by the electrical variaion in the nerve has been called, and this current he found to pass along the nerve not in the same direction as the impulse but in the opposite direction. By stimulating the sciatic nerve he found that such a negative variation existed not only in the posterior roots but also in the anterior roots. In normal conditions stimulation passes along the posterior and then into the anterior roots; this indicates that both the sensory and the motor fibres may conduct the impulses in both directions. Thus the nerve tissue is capable of ~~of~~ conductivity in two directions, although in normal circumstances the stimulation only passes in one direction, but this is due to the fact that the impulse originates only at one end. This is an important physiological point because the central nervous system may be stimulated in connection with the impulses from the muscles not only along the sensory but even along the motor paths and even in the central nervous system the transmission of impulses may take place in either direction along what are called usually the central and motor tracts. In connection with the conductivity of impulses we find great differences in different tissues. In the case of the cold blooded animals the nerves are capable of conducting impulses much more slowly than the nerves of warm blooded animals. In any animal the nerves are capable of conductivity more rapidly than the muscles, the striped muscles more quickly than the unstriped muscles; and even in a single fibre the different parts are capable of transmitting with different degrees of rapidity, the principle being laid down that the more differentiated the cell substance is the greater the rapidity of its conductivity. Biedermann lays down this principle that conductivity is increased as the power of mobility and the readiness to respond to external stimulation are increased.

(a) Muscle. The process of conductivity cannot be followed by the eye and hence we can only calculate the rate of the process from its results. In the muscles however there are certain changes taking place as

the impulse is transmitted so that we can estimate the rapidity from the changes in the substance. By irritating a muscle at one end contraction does not take place over the entire mnscle but there is an alteration originating at the point of irritation and transmitted over the length of the muscle fibres. Along with the shortening of the muscle we have its thickening and it is possible to follow out this thickening as it passes from end to end. In the striped muscle the rate of conductivity is so quick that it seems to pass over the entire muscle at one and the same time. That this is not so can be proved by the use of registering apparati. If two levers are placed in connection with the two ends of a muscle while the ends of the levers are in connection with the kymograph, and if during the revolution of the kymograph stimulation is applied to one end of the muscle the kymograph will indicate that the lever at the end of stimulation is the first to give response, indicating that a thickening takes place at the point of stimulation and that a certain time is occupied in the transmission of this along the length of the muscle. Bernstein has used this process in connection with the registration of the period of latency. He attached a lever to the end of the muscle so that as soon as the muscle began to thicken the kymograph began to record. In one case he stimulated the muscle at the point from which he made a record of the contraction and immediately afterwards he stimulated it at the other end. By measurement he knew the distance between the two points of stimulation and he estimated the rate of conductivity by calculating the difference in the two periods of latency. In connection with the semi-membranosus muscle of a frog he found the rate of conductivity to be 115.76 to 157.2 feet per second. In the case of the sartorious muscle Hermann found the rate of conductivity about 116 feet per second and this is taken as about the average rapidity in the case of the muscle of a frog. According to these experiments it is found that the wave of contraction passes over the muscle from one part to another. It is easy to find out how long the contraction takes when passing over a muscle from point to point so that we can find the rate at which the contraction moves and from this we can estimate the contraction wave length. According to Bernstein the length of a wave of contraction in the case of a frog's muscle is about 198 to 380 millimeters. In the case of the normal striated muscle it is not more than about 40 millimeters and as the stimulation takes place normally in connection with the nerve at the center of the muscle fibre the stimulation will pass through the muscle in two directions so that the entire stimulation of the muscle fibre would represent two rapid wave contractions in opposite directions. The rate of conductivity varies in different kinds of muscle and in different animals, estimates having been formed by various experimenters. In the case of the human muscle Hermann estimates the rate of conductivity from 10 to 13 meters per second; in the white muscle of the rabbit from 5 to 11.4, in the red muscle of the rabbit 3·4; in the sterno-mastoid muscle of a dog from 3 to 6; in the cardiac muscle of a frog .1 and in the smooth muscle of the ureter of the rabbit .02.

(b) Nerves. As we have seen nerve tissue represents a more highly different iated bioplasm and hence the conductivity is more rapid. It is so rapid that some physiologists have questioned the experiments that have been make in connection with the tests of the rapidity. In nerve tissue no obsevrable changes take place so that we can calculate the rate of conductivity only by the results in connection with muscle or in connection with the electrical variations that spread over the nerves. In connection

with the central nerves very little is known of the rate of conductivity although several attempts have been made to discover the rapidity with which the stimulations travel by exciting the sensory nerves at two different points and watching the time when the reflex result takes place. In connection with the human system experiments have been made in connection with the time that intervenes between the application of an irritation and the sensation which results. Arrangements have been made by which in this experiment a signal is given when the sensation is felt, this is called the period of reaction. It has been found by testing the reaction period that an impulse travels along the sensory fibres at the rate of 36 meters per second although Cattell finds that in the case of the median nerve the rate varies from 21 to 50 meters per second and in the case of the tibial nerve from 31 to 65 meters per second. These differences in the rate of stimulation are said to be due to the differences in the terminals of the nerve fibres in connection with the skin although it is claimed that part of the difference is due to the receptivity of the central nervous system. It has been concluded that in the case of the sensory fibres in the human subject the rate of conductivity is about 35 meters per second.

In the case of the motor nerve Helmholtz estimated in connection with experiments the rate to be in the case of a frog about 27 meters per second. He made use of the Pouillet method for measuring brief periods of time. As soon as the current in connection with a primary induction coil is broken and the nerve in connection with the secondary coil is subjected to a shock a current is thrown into the coils in connection with the galvanometer. Immediately the contraction of the muscle produced by the stimulation passing from the nerve interrupts the circuit of the galvanometer. The deviation found in the galvanometer varies with the period during which the circuit is closed and this is taken as an index of the period intervening between the excitation of the nerve and the contraction of the muscle. By stimulating the nerve at two points of known distance the difference in time is taken to indicate the time that is necessary to conduct the impulse between the two points. Helmholtz afterwards applied a more direct method of registering the muscular contraction and he made use of this to find the rate of motor nerve conductivity. By exciting the nerve as close to the muscle as possible and registering the muscle contraction, and then irritating the nerve as far from the muscle as possible and registering the contraction he finds that by calculating the difference in time between the period of excitation and the contraction in the two cases, knowing the distance between the two points, he can estimate the time necessary for the impulse to pass from the one point to the other and therefore the rate of conductivity. He applied this principle to the human subject by registering the muscle contraction of the fore part of the thumb noting the difference in the time of the commencement of the contraction in the case of the stimulation of the median nerve at two different points along its path. In this experiment he found that the average rapidity of an impulse along the motor path was 34 meters per second. These results of Helmholtz represent the average rate of conductivity in the case of human nerves. It has been found in more recent times that by raising the temperature of the body or by stimulating very rapidly, the rate of conductivity may be increased up to 100 meters per second. It is also found that the physiological functions of the nerve determine to a large extent the rate of conductivity. In the

case of the vagus nerve supplying the laryngeal muscles that move very rapidly it is found that the rate is 66 meters per second whereas the vagus fibres regulating the oesophageal muscles is only about eight meters per second. It is claimed by some physiologists that the medullated fibres transmit their impulses very much more rapidly than the non-medullated, this conclusion being based on some experiments in connection with the non-medullated fibres in vertebrate animals. It would seem that in general the rate of conductivity in the case of the sensory and motor nerves in the human subject is about the same, namely 34 to 35 meters per second.

The nature of the neural impulse is not known; it is spoken of as a neural commotion because in some way it is connected with the molecular action that takes place in connection with the neural substance. Conductivity is destroyed by anything that interferes with the neural continuity or anything that interferes with irritability at any part along the nerve path, because the impulse requires the integrity of the axis cylinder. On this basis certain principles have been summarized as forming the laws of conductivity, (1) the nerve must preserve its continuity and integrity; (2) the conductivity takes place along the isolated path of continuous nerve fibres no impulse being transferred to contiguous fibres; (3) there is a double conductivity in connection with the sensory and motor fibres; (4) there is an independent excitability in the nerve fibres, the effect of stimulation being regulated by the character of the nerve terminal so that in in case the nerve terminates in a muscle it is manifest in movement, if it ends in a gland in secretion, and if it ends in the central nervous system it manifests itself in sensation. We have seen that double conductivity is a characteristic of both motor and sensory fibres; while in the sensory fibres the impulse passes afferently and in the motor efferently in normal conditions, yet there is capacity of conducting in both directions. By stimulating either a motor or sensory nerve along its path a stimulus is transmitted in both directions, above and below the point of stimulation. In the case of the electric animals, by stimulating the posterior free end of the efferent nerves of the malapterurus the stimulation passes to the branchings above the point of stimulation resulting in an electric discharge. In the sartorius muscle there are no nerve fibres at the upper and lower ends; by cutting off the lower part and dividing the lower part of the muscle in two when suspended and then stimulating one part of the divided end the stimulation passes up along the motor fibre and then down into the other part producing contraction. Kuhne found that by dividing the gracilis muscle into two parts so as not to injure the nerve supplying the parts, by stimulating the one part of the muscle and its nerve contraction results in both parts, this being caused by the conduction of an impulse afferently along a motor fibre.

Conditions Which Affect Conductivity.—By stimulating the motor nerve at its central end there is originated a neural commotion which is transmitted along the nerve with a certain rapidity. This rapidity may be subject to modification by various conditions, (a) temperature. It is found to be lessened by cold; by the cooling of the motor nerves Helmholtz found that the rate of conduction was lowered and by heating them it was increased. In the case of man, by changes of temperature variations in motor conductivity were found from 30 to 100 meters per second. The same thing is found in the case of the motor nerve, both of vertebrates and invertebrates, the variation in temperature being from about 10 to 20

degrees C. In the case of a sensory fibre it is found that by heating and cooling them variations in rapidity take place from 35 to 100 meters per second. By cooling the sympathetic and vagus nerves the heart beat of the frog is decreased and by heating them it is increased. Heat seems to exercise a favoring influence on conductivity, but this is not absolute as it is found that by heating the motor nerves of the sciatic to 41 degrees C. they lose their power of conductivity, although this is temporary because by cooling they are restored. If the temperature is raised to 51 degrees the conductivity is destroyed. Different nerves have their power of conductivity suspended or lost at different temperatures and this is true of different animals. The motor fibres of the sciatic in the dog lose conductivity at 6 degrees those of the cat at 3 degrees and those of the frog at zero C. Different fibres in the same nerve are affected differently by different temperatures and this is used to distinguish the different fibres. The vaso-constrictor fibres of the sciatic conduct between two degrees and 47 degrees the dilator fibres continuing to conduct both below and above those limits. By the application of cold to a part of the nerve the conductivity is lost because an obstruction exists at that part. If a part of a nerve is heated the rate of conductivity is increased in passing through the heated portion. This has been taken as an indication that the axis cylinder passes through chemical changes in connection with conductivity, but this does not seem to follow because conductivity does not produce exhaustion in the nerve. It is found that high or low temperatures have an effect in lessening and increasing the rate of the normal transmission of impulses, the average temperature that seems to aid transmissibility being about 15 to 25 degrees C. (b) Mechanical stimulation. Compression diminishes the power of conductivity. By compressing the ulnar nerve as it passes over the elbow the region which the nerve supplies is deprived of the neural impulse. The evidence of this is found in the fact that more effort is necessary to move the muscles when there are no sensations passing from the hand. Sensory fibres seem to have less power of resisting pressure than motor. If the compression is applied slowly the nerve may be paralyzed without irritation but as soon as the pressure is taken away the function is restored and accompanying restoration is irritation. The cause of the loss of function resulting from compression is not known but it is important because it forms a basis of inhibition as applied Osteopathically. The same effect may be secured by stretching a nerve; if the tension becomes severe the conductivity may be entirely destroyed. By stretching a nerve the sheath surrounding the axis cylinder is elongated and therefore the callibre is diminished so that the pressure brought to bear upon it is greater resulting in a loss of conductivity or its suspension. (c) Chemical action. Conductivity is greatly altered by anything that changes the composition of the neural substance. Any chemicals which increase or decrease irritability have the same effect on the conductivity as a general rule. The effect of curari is to lessen transmissibility; the effect of alcohol and ether is to lessen or destroy conductivity without interfering much with irritability; CO_2 if excessive destroys irritability without affecting conductivity.

(d) When a muscle is dying there is an important modification of the rate of conduction. In normal conditions conductivity takes place so quickly that the entire muscle seems to contract at one time. The transmission of the impulse however may be lessened and even prevented according as certain changes are found associated with the muscle. If a

muscle when dying is stimulated by a mechanical blow the result is that a swelling is produced locally; by lightly tapping the muscle there will be found a contraction wave passing over the part of the muscle that is tapped, indicating that the contraction is entirely local. In the case of a nerve when dying the rate of transmission is gradually lessened until when degeneration is complete conductivity is entirely lost. (e) Electric influences. By the passage of a constant current a change takes place in the conductivity as well as influencing irritability, influencing particularly the rate of conductivity. Feeble currents do not affect or affect only slightly conductivity whereas strong currents destroy the power of conduction. By increasing the strength the effect is noticed around the positive pole manifested in the slow passage of the impulse. This becomes more pronounced as the nerve is laid open to the current and as the current is increased. The loss of conductivity is accompanied by changes at the point of entrance and of exit in the case of the nerve hardly any change being found in the intervening region. Engelmann in experimenting on the unstriped muscle found that conductivity was lessened at the positive pole, where a weak current was used at the negative pole the current increase involving an increase of conductivity. When the current becomes very strong conductivity was entirely lost. The diminished power to conduct is associated by some with a fatigued condition but this has not been fully proved at least in the case of the nerve. Exhaustion certainly does not interfere with the conductivity of muscle but in the case of the nerves it is not known that they become fatigued. It is true that certain physical and chemical changes take place in the nerve when a strong current is passed through it but the cause of the loss of conductivity can not yet be directly associated with these changes. The alterations that take place in the conductivity of nerves by the use of strong currents partly explains the reason why the closing of the ascending current and the opening of the descending current do not excite the muscle. The changes produced by strong currents on irritability and conductivity of muscles and nerves is of value in connection with the therapeutic use of electricity. If it is desired to make use of only one pole a small electrode may be applied directly over the part to be affected the other electrode being a large one placed at an indifferent part of the body. The density of the current as it enters or leaves the body is determined largely by the size of the electrode and therefore the effect of the action is also determined by the size of the electrode.

Nature of Conductivity.—Some experimenters have tried to find out the changes taking place in connection with conductivity. They have stimulated the nerve for a long period electrically and carefully examined it to find out if there is any accumulation of waste substance. In the gray matter of the spinal cord it is found that when activity is continued for a long time it becomes acid in reaction but the same thing is not found in the white matter which forms the nerve fibres. Attempts have been made to find other changes supposed to be associated with conductivity. It is not found that any appreciable change of temperature takes place in connection with conduction. Experimenters have tried to find out whether a nerve becomes exhausted by conductivity, the most of the experiments being made in connection with the motor nerves, the resulting contraction being taken as an indication of exhaustion. As the muscle becomes fatigued attempts have been made to isolate the nerve from the muscle except at the opening and closing of the experiment. These at-

tempts however have been only partially successful as the muscle and the nerve terminal have been deprived of activity by means of curari or ether. Some have tried to make use of the current of negative variation as an index of nerve activity. Others have taken the vagus nerve to try and find if by long stimulation it could be made incapable of inhibiting the heart, the heart muscles being kept from stimulation by the use of atropin. The results of these experiments have not been positive so that it can not be stated whether a nerve may or may not be fatigued. It is certain that nerve conductivity is interfered with if the blood supply is interfered with and this may be taken as an indirect proof that there is continually metabolism going on in connection with the nerve tissues.

A great number of theories have been formulated in regard to the real nature of the conducting process. Some have claimed that the nerve acts like a rope; others that it is a tube through which a fluid moves and that the fluid goes through oscillatory movements; others have claimed that it acts like a wire in conducting electricity the nerve consisting of certain molecules which have a definite influence upon each other in the transmission of the neural impulse; others claim that it is composed of chemical substances which act upon one another producing certain results much as an explosive substance does when producing an explosion; while others claim that the molecules of the nerve pass through physical changes similar to those that take place in connection with the transmission of light. So far as known to us the only function of the nerve is that of conductivity from periphery to centers or vice versa or from center to center. Normally these neural impulses hardly ever originate along the path of the nerve but arise either at the periphery or in connection with the central cells. The nature of the neural impulse is unknown. We do know that some change takes place manifested in the electrical variation and that this change is transmitted along the nerve manifesting itself efferently in contraction or inhibition in connection with the muscles, in secretion in connection with the gland and afferently in sensation or in connection with reflex muscular actions, glandular and secretory activity. Whether it is chemical, electrical or purely molecular nothing definite is known. There is no doubt that certain chemical changes take place in the nerve, so much so that if the changes involved in the blood circulation are cut off the nerve loses its irritability. The metabolic changes however of the nerve are not so great as those found in connection with the muscle as no appreciable CO_2 has been found given off in connection with nerve activity. Conductivity is not changed so materially as irritability, hence as we have seen close to the negative pole an excitation is more easily aroused, indicating an increase of irritability; whereas it is more difficult ~~to~~ for an impulse to pass in connection with the negative pole than in the normal nerve indicating the lessening of conductivity. The presence of CO_2 seems to lessen the irritability of the nerve without materially altering its conductivity. Alcohol has the effect of increasing irritability without changing the conductivity. Munk has found that when the sciatic nerve is dying there is a difference in irritability at different points of the nerve so that at one point a very strong stimulation has no effect while a feeble stimulation close to the central part produces muscular contraction. This was taken as an indication by Munk that the nerve propagation differs from the process of origination so that the transmission takes place by the stimulation of each neural element by its adjacent neural element. There seems to be a capacity for transmission whatever

that means, as we have found in artificial stimulation the impulses may be conveyed in both directions along the nerve. In the case of the normal nerve there is a trophic influence exerted along the afferent nerves and it is also claimed that the retina can be stimulated by impulses passing along the optic nerve in the wrong direction. This does not indicate however anything direct as to the nature of the neural impulse.

There is a difference in different individuals in the time required for neural activity and this is said to indicate that the neural process is different in different persons. In voluntary action the time required is distributed into three processes, the voluntary action in the brain, the transmission of the motor impulse along the spinal cord and nerves and the excitability of the muscle to contractility. In the case of a sensation aroused by sensory stimulation there are three stages, the receptivity of the impression in the sensory organ, the transmission of the impulse along the nerve to the brain and its reception in the brain and transformation to a conscious sensation. That this neural impulse is not uniform in its action is claimed from the fact that in the spinal cord there is a difference of rate as compared with the nerves. Burckhardt determined this rate for the spinal cord by comparing the time of the passage of a voluntary impulse through the sciatic and ulnar nerves which leave the spinal cord at different points. The impulse when it leaves the brain travels along the cord and as it is known how fast it travels in the peripheral nerves the difference in time represents the rate of passage in the cord. For example, an impulse that excites the interosseous hand muscles goes through the cervical part of the cord, the lower cervical nerves, the brachial plexus and along the ulnar nerve; an impulse that contracts the quadriceps extensor goes through the cervical and dorsal regions of the cord, the lumbar plexus and along the anterior crural nerve; the latter impulse travels along the spinal cord about three times that of the former so that the difference will represent the rate of transmission along the cord. It is found from this that the conductivity of the cord represents a much slower movement than the regular nerves, the normal rate being from 8 to 14 meters per second. A difference has been found on the two sides of the body as represented by the right and left lateral halves of the cord, the left being from one to four meters quicker than the right. In the case of sensory impulses traveling through the cord there is very little difference between the cord and the nerves, the average being about 42 to 47 meters per second. There is a difference among the sensory impulses, tactile impressions traveling much faster than those of pain, the latter moving about 12 to 13 meters per second. In connection with the brain it is claimed that longer time is required for the transmission of impulses than the cord or the nerves. This time can be estimated by the time from the impression to the time when the impulse reaches the brain, deducting the period necessary for the stimulation and the time occupied in the nerves and the spinal cord. The time required to perform a voluntary motion of the foot in connection with a signal is estimated as follows: (1) hearing the signal .01 of a second, (2) action in the brain involving reception and volition .112, (3) transmission along the cord .044, (4) transmission along the sciatic nerve .044, (5) period occupied in muscle contraction .01, amounting in all to .22 of a second. Among different individuals there are differences in the rate of impulses producing differences in the period necessary for perception and volition. This was first found in astronomical observations where differences were found in recording the

time of the transit of a star across the instrument of observation. The difference in time was ascribed to the difference in the nervous mechanism of the observers. This is proved by the use of instruments to record exactly the instant of passage when it is found that a variation exists between the record of the instrument and the record of the individual, this being regarded as a personal equation. This is taken as an indication that differences exist in the individual which either retard or hasten the conduction of neural impulses. This represents a physiological peculiarity and may vary even in the same individual under different circumstances. All of these seem to indicate that nerve commotion travels slowly compared with the rate of light or sound in the physical sense so that all kinds of nerve activity travel very slowly.

As to the intrinsic nature of the neural impulse it unis known. The impulse is analogous in some respects to the electric current passed along a conductor and also to the chemical changes taking place in connection with the decomposition of a delicate band of guncotton but the analogy fails in all these cases. In connection with this it is found that the nerves are not equally irritable at all points along their course nor in all the different branches. There is a difference for example in the excitability of the motor fibre to the extensor muscles and the flexor muscles of the limbs and also between the vaso-dilator and vaso-constrictor fibres. By stimulating the sciatic nerve flexure will result first and afterwards as the current increases flexure will be changed into extension. This indicates that the flexor nerve fibres are more easily excited than the extensor fibres. The vaso-constrictor action is secured more easily than vaso-dilatation. The unequal irritability of excised nerves is said to be explained by the fact that a local injury takes place in connection with the excision, in other words there is a mechanical stimulation in connection with the injury. Pfluger advanced what is called the avalanche theory to the effect that the stimulus increases in force as it progresses along a motor nerve so that a feeble stimulus originating far away from the muscles would have a greater effect on the muscle than a stronger stimulus originating nearer to the muscle. This theory, however, has been set aside by more recent experiments the stimulus in its conductivity remaining constant. According to the Ritter-Valli law the nerve is more irritable immediately after excision close to the cut part than it is farther away from the division. After a time the heightened irritability gives way to lessened irritability which is gradually lost, this loss of irritability being manifest in progress towards the muscle. This has no bearing on the difference of excitability in the case of living nerves. In the case of a nerve there is no evidence of mechanical, thermal or chemical changes the only change of which there is any evidence being the current of action which of itself does not indicate any chemical change, although it is supposed to indicate the production of CO_2. The nerve represents a force conducting medium and in this sense is practically exhaustless. Fatigue as we have seen is practically localized in the neuro-muscular end plate so that it is an indication of the exhaustion of the nerve or its incapacity for conduction. In regard to the change in a nerve in connection with the nerve impulse on the analogy of muscle and nerve it would seem as if the passage of an impulse involves a chemical change. There is no evidence that such a change takes place, not even that an acid reaction is developed in the nerve. The gray matter of the central system is slightly alkaline during life and after death becomes acid, the white matter which is made

up of fibres continues to be during life and after death either alkaline or neutral. The only change then that is appreciable is the electrical one. The only thing that can be recognized in connection with the neural impulse is this electrical change. When a nerve is taken out of the body and subjected to stimulation very similar changes are found to those taking place in the muscle. There is an equator in both muscle and nerve which electrically is positive to the cut parts of the muscle and nerve and as the neural impulse passes along the nerve the nerve current passes through a negative variation as the natural current in muscle passes through the negative variation during contraction. It is questionable if natural currents do exist. When the muscle and nerve are in a normal condition they are said to be iso-electrical so that during muscle contraction and during the passage of an impulse through a nerve there is a current of action representing the negative variation. This change represents the important variation taking place in connection with the passage of an impulse. This impulse may or may not be the same as the current of action but both the current of action and the impulse travel with the same rapidity and are subject to the same variation. Both travel in an undulatory manner representing a maximal and minimal variation in passing along the nerve. When a nerve is stimulated at the middle of the nerve path the current of variation is propagated in both directions and this is taken as an indication that the same thing takes place in connection with the impulse both in the sensory and motor nerve. We are not able therefore absolutely to identify the nerve impulse with the current of action found in connection with the nerve although there is a close analogy between the two.

SECTION VI. The Physiology of Nervous Tissue.

We have discussed the properties of muscles and nerves in connection with the muscles. Before discussing the phenomena exhibited by the muscles and nerves in connection with heat, chemicals and electricity we must consider the physiology of nervous tissue. The neural mechanism bears such a close relation to all the tissues of the body and their functions that it is very important. Under nervous tissues are included not only nerve fibres but also the nerve centers with one of which each nerve fibre is connected by one of its extremities. The other extremity of the nerve fibre, at least in many cases, terminates in some special structure termed an end organ and these nerve organs may be considered in connection with the nervous tissues. Many of these end organs are affected by certain special stimuli and different nerve centers have different functions allotted to them. It will therefore be convenient here to discuss only those phenomena of nervous action which are exhibited more or less by all nerve centers and all nerve fibres. Certain special effects will be explained concerning nervous action with the physiology of the various organs and of the central nervous system. With the latter it will also be convenient to consider the function of these specialized structures and organs through which special agents, for example, odors, light, sounds etc., are able to stimulate nerve fibres. In connection with the nervous mechanism there are four different kinds of evidence available, (a) that furnished by anatomy from the origin, course and relations of the different parts of the system; (b) that furnished by a histological examination of the structure of the nerve both in its embryo and adult condition;

(c) the experimental facts discovered by physiologists when the nerves are divided and the stimulation is applied to the parts; (d) the observations of clinical physicians and surgeons and the postmortem results of pathological examinations. For a long time the anatomical knowledge was simply confirmed by clinical experiences but in recent years the experimental methods have opened up a wide field of information regarding the nerves. By laying open a nerve, dividing it and subjecting it to stimulation interesting results were obtained in connection with the feeble and strong currents. In this way clear differentiation was found between the sensory and motor nerves and a clear distinction was made in the functions ascribed to the cranial and the spinal nerves, as well as the influence of certain nerves or definite organs of the body. Thus the anatomists, histologists, physicians and surgeons have all been united in the attempt to open up the difficulties of the neural economy. The nervous system consists of (a) the brain and spinal cord forming the central nervous system; (b) the nerves that pass from the central system to the different parts of the body, those in relation to the spinal cord being called spinal and those in relation to the brain cranial nerves; (c) ganglia that are found distributed along the nerve paths and (d) nerve terminals which bring the nervous system into close relation to the muscles and organs of the body. In the body there are two nervous systems which are, however closely related to one another at many points, (a) the cerebro-spinal consisting of a brain and spinal cord, cranial and spinal nerves in connection chiefly with the integument, organs of special senses the voluntary muscles, etc. (b) The sympathetic consisting of small nerve centers or ganglia and the nerve fibres in connection with them the majority of the fibres joined by fibres forming a chain on each side of the vertebral colum.n The sympathetics are chiefly in relation with the blood vessels and the viscera. The nervous system in man consists essentially of three parts, nerve centers, terminal organs and the nerve fibres joining together the central and terminal organs. A nerve center always contains nerve corpuscles which are supported by a delicate neuroglia. Each nerve corpuscle is nucleated, destitute of a cell wall and has a varying number of branches or poles one of which is continuous with the nerve fibre, the axis cylinder. The different varieties of nerve corpuscles are (1) bi-polar in the ganglia on the posterior roots of the spinal nerves; (2) tri-polar or pyramidal in the gray matter of the surface of the cerebral hemispheres; (3) multipolar in the gray matter of the spinal cord; (4) the pear or flask shaped cells called also the tad-pole cell in the gray matter of the cerebellum. The nerve fibres are of two kinds, (a) the white or medullated found chiefly in the cerebro-spinal system and (b) the gray non-medullated in the sympathetic system and in the olfactory nerve. A nerve or nervous cord as found in the body is composed of an outer sheath from which partitions pass in separating different bundles or fasciculi of nervous fibres. Each little bundle has also a separate sheath of its own composed of nerve fibres. A white or medullated nerve fibre is a narrow band varying in diameter from one-twelve thousandth to one-fifteen thousandth part of an inch, of double contour and a slightly sinuous outline consisting of (a) a delicate transparent outer sheath the lining membrane or primitive sheath; (b) on the deep surface of these are nuclei; (c) contained within this sheath a semi-fluid matter which after death or under the influence of acetic acids is found to be divided into two parts, [1] a central albuminous thread, the axis cylinder. This is the essential conducting part of the nerve from the central

extremity where it is continuous with the nerve corpuscle. It passes continuously along the course of a nerve and it is only when close to its peripheral termination that it breaks up into fine branches. [2] Under a high power microscope longitudinal striae may be seen. Surrounding the axis cylinder is a less dense substance known as the medullary sheath or white substance of Schwann. This contains a large proportion of protagon, a substance in which both N and P are constituents and which yields a large amount of fatty matter. When it is stained black with osmic acid the white substance seems to be interrupted at regular intervals these interruptions being termed the nodes of Ranvier. The parts of the nerve between the nodes are called the internodes. A single nucleus on the surface of the primitive sheath is found in each node. The non-medullated or gray nerve fibres are flat narrow bands with numerous nerve nuclei. There is no white substance of Schwann and the fibres often branch off and unite with neighboring fibres. There is an outer covering or membrane which represents the neurilemma. In the spinal cord we find a number of segments along the cord axis each segment sending off a pair of spinal nerves. The same segmentary division exists in the brain, the cranial nerves representing this division although it is less complete than that of the cord. In connection with each spinal nerve we find two roots. Each segment of the cord consists of a gray internal part and a white external part, the anterior root being given off from the anterior part of the gray matter and the posterior root from the posterior part. The posterior root passes into the spinal ganglion uniting beyond the ganglion with the anterior roots to form the main trunk. The posterior root contains sensory fibres and the anterior root motor fibres so that the main trunk represents a mixed nerve. In the division of the fibres of this trunk branches are sent off to the skeletal muscles and the cutaneous sufaces, the motor fibres being united with the muscle fibres and the sensory fibres terminating in epithelial cells, while others after dividing into minute processes and forming plexuses terminate in the tssues of the skin and the skeletal muscles. The cutaneous nerves are called somatic to distinguish them from the visceral nerves that are called splanchnics. After the mixed nerve leaves the spinal canal a branch is given off that runs as a ramus communicans nerve into the sympathetic ganglia, the sympathetic system representing an enlargement of the splanchnic branches of the spinal nerves. In this way the splanchnics are sent to the visceral organs some of them going through the ganglia, most of these splanchnics being centrifugal fibres carrying impulses from the central system to the viscera, although a few are centripetal carrying impulses from the viscera to the central system. All the fibres from the sympathetic do not go to the viscera for some return to the spinal nerve and go along the somatic nerves while others go back into the cord. Some nerves passing to the blood vessels affect the calibre of the vessels and are called nerves of vaso-motion, those which constrict being called vaso-constrictor. These vaso-constrictor fibres pass from the central nervous system to the splanchnic and sympathetic system, some passing to the blood vessels of the viscera and others turning back to pass along with the somatic nerves to the blood vessels of the cutaneous surfaces.

A nerve is essentially the elongation of a nerve cell, the axis cylinder, which in the medullated nerve is the essential part and in the non-medullated nerve forms the entire nerve except the neurilemma, being the continuation of the axis cylinder cell process. A nerve then consists of nerve

fibres connected together in connection with connective tissue containing blood vessels and lymphatics. The spinal and cranial nerves are chiefly medullated some being non-medullated, while the sympathetic nerves are chiefly non-medullated. In the medullated nerves the fibres are enclosed in an epineurium sending out septa into the nerve. In the non-medullated fibres a perineurium binds together the fibres, In the larger sympathetic trunks in the liver and kidneys are found tubular lymph spaces between the fibres. In the large nerve trunks there is a distribution of capillary blood vessels ramifying in the perineurium and epineurium, each fibre being surrounded by a lymph space, continuous with the sub-dural and sub-arachnoidal spaces in the brain and spinal cord. Thus changes of pressure in the lymphatic circulation affect the nerve fibres. The ganglia represent small cell groups along the path of the peripheral nerves. In the ganglia there are minute bundles of fibres with groups of ganglion cells collected together either in rounded or elongated masses. Around the ganglia there is a sheath of connective tissue which forms the continuation of the nerve perineurium and septa of connective tissue sometimes into the ganglia. Capillaries are found very abundantly in the ganglia and in connection with the cells we find great vascularity showing the necessity for a constant supply of blood in connection with nutrition. In the cerebro-spinal ganglia the cells are large and rounded, each cell being surrounded by a layer of flattened cells continuous with the sheath of the medullated nerves. The ganglion cells are unipolar, one of the processes coming from the cell and afterwards dividing into two branches. The nerve fibres in connection with the gangliaare medullated, but it is not known how the fibres are arranged in the interior part of ths ganglia. Gaskell has shown that when a medullated nerve enters the ganglion it loses its sheath and leaves the ganglion non-medullated. Among these ganglia we find the Gasserian in connection with the fifth cranial, the jugular ganglion in connection with the pneumogastric, the petrosal in connection with the glosso-pharyngeal, the auditory ganglion in connection with the auditory nerve, the geniculate ganglion in connection with the facial nerve and the spinal ganglia. In the sympathetic ganglia the cells are smaller and they are multi-polar. The fibres that are associated with these ganglia are medullated and non-medullated although nothing is known as to their relation with the ganglion cells.

In regard to the nerve terminals the terminators are the agents of nervous impulses the fibres being the media of communication between the terminators. One set of these terminators is found on the body surface and is capable of receiving influences from the outside. These receivers of external stimuli are very varied in character as they are capable of receiving the various kinds of intrinsic stimulation. They may be either distributed over the whole surface so as to be brought into contact with external stimulation or they may be localized and specialized so as to receive sonorous, luminous, odorous and gustatory influences. In the latter cases the terminators are localized into one part forming the complex organs of sense. Another kind of terminator is found embedded in the deeper structure acting as local distributors of impulses, for example, the skeletal nerve plates, the ganglionic net-work in the intestinal walls. In many cases the connection between the tissues and the nerves is not yet understood. Another class of terminators is found in the ganglion cells in which the cells are grouped together, these constituting the central terminators found in the cerebro-spinal system or in the ganglia centers.

These nerve cells have all processes branching out from the centers as a means of communicating with the nerve fibres. In this way the connection with the terminators is complete throughout the entire nervous system. While a nerve may be stimulated along its path the stimulation is usually applied in connection with a special organ capable of receiving a particular kind of stimulation. In vision, for example, there is a terminal organ in the retina the optic nerve representing the conductor and the brain the organ of reception. Light does not affect the optic nerve but the light acts specifically on the retina the stimulation of the retina resulting in the stimulation of the fibres of the optic nerve. The function of the terminal organs may be described as that of a mechanism for setting free stimulation. They do not change physical energy into nerve energy but they promote the nerve action in connection with external stimulation.

It has been shown that nerve fibres may be aroused to activity either directly or as a result of changes occurring in nerve centers. The nerves do not possess the power of originating impressions so that their function is purely one of transmission. Those which convey impressions inward to nerve centers are called afferent and those along which impressions travel outwards from nerve centers are called efferent. That some change is produced in the nerve fibre as a result of stimulation and that this change passes along the fibre has been already shown. It may be demonstrated by stimulating a motor nerve at some distance from the muscle when the muscle will contract. The nerve may be said to respond to a stimulus by becoming excited and this state of excitement is conducted along the fibre. Hence the fibres are said to possess excitability and conductivity. The essential part of the fibre is the part in which excitability resides and along which the impression travels, namely the axis cylinder. It is not known what the exact nature of the changes taking place in a fibre as a result of stimulation are, but the comparatively slow rate at which the change travels along the fibres seems to indicate that it is not of the same nature as an electric current. Whatever is its nature the actual change in the nerve fibre appears to be identical whether the impression is passing afferently or efferently. The difference in the ultimate effect produced does not depend on the difference in the fibre or in the nerve current but on the varying nature of the structure in which the nerve terminates, for example, muscles, nerve centers. Various circumstances influence the degree of excitability, as for example, the state of nutrition, the alternate period of rest and activity, temperature, the passage of a constant current of electricity. It is also known that the further the motor nerve is irritated from the muscle the greater is the excitability at the one end and the contraction at the other, this is Pfluger's law of contraction. If the sciatic nerve of a frog connected with the isolated limb is stretched over two wires passing from the positive and negative poles of a battery with a distance of one and one-half inches between the wires; and if a key is interposed in the circuit a current will pass along one and one-half inches of the nerve when the key is closed and cease when the key is opened. By having a communicator or receiver in the circuit we can send a current up and down a nerve at will. Arrangements may also be made for irritating the nerve by another pair of wires coming from an induction machine either near the negative or positive pole of the current coming from the battery. It will be found that near the negative pole nerve excitability is increased while near the

positive pole it is diminished, that is, the nerve near the negative pole is more excitable than in the normal state, whereas nearer the positive pole it is less excitable, indicating that one of the physiological properties of nerve fibre has been changed by the action of a continuous current. An electrical current applied to a nerve produces stimulation only at the point of entering and leaving it. During the passage of the steady and continuous current the nerve is said to be in the electrotonic state. In this state some of its properties differ from the normal, the portions of the nerve around the positive pole being called anelectrotonic; the portion around the negative pole being called katelectrotonic. In the former case electrical tension is increased while the excitability and conductivity are diminished; in the latter case the changes are the reverse. Between the two parts when the nerve is in the electrotonic state there is a neutral point of indifference in which the properties of the nerve seem to be unchanged and the position of this point seems to depend on the strength of the current. When the current is strong the point is near the negative pole, that is, the nerve near the negative pole is anelectrotonic, the excitability being decreased; when the current is weak the point is near the positive pole, that is, the nerve near the negative pole is katelectrotonic, the excitability being increased; if the current is medium the point of indifference lies midway between the poles and the excitability is therefore normal. This explains the reason why on closing the current a feeble current gives contraction because a large portion of the nerve close to the negative pole becomes katelectrotonic and therefore produces stimulation. If the current is strong a stimulation takes place on opening because a large portion of the nerve close to the positive pole is anelectrotonic and therefore produces stimulation. When the current is moderate there is a contraction both on opening and closing because the electrotonic condition is produced midway between the poles. Chauveau has experimented on placing the one pole on the nerve and the other on some other part of the body. He finds that the current possesses in this case a definite intensity depending on the physiological nerve condition; by decreasing the intensity below the normal, motor nerves are affected more strongly by the negative than the positive pole, while the reverse is the case if the intensity is above normal. In the sensory nerves more pain is produced in connection with the negative than the positive pole and from this he concluded that the positive pole is stronger on the motor and the negative stronger on the sensory nerves.

In connection with nerve tissue it is important to notice the physical, chemical and vital properties (1) Physical properties. The gray matter is found to be soft and diffluent, even the white matter has little cohesion or consistency. Any slight degree of firmness, cohesion or consistency in the nerve center is due to the delicate neuroglia, a kind of cement formed of a substance allied to keratin; a whitish homogenous substance of epithelial origin which supports the nerve corpuscles binding together individual nerve fibres and ganglion cells. In nerve fibres the contents of the primitive sheath or neurilemma exist during life in a semi-fluid condition and the toughness and strength of the nerve trunk is dependent on the corny tissue of granular matter or spongy horny substance binding together the nerve fibres. The elasticity of nerves is not perfect. The white matter consisting of nerve fibres absorbs fluids containing saline substances in different proportions, for example, NaCl is not absorbed at all, sulphate of soda only very slightly while the salts of

potassium are absorbed very freely. (2) Chemical properties. The chemistry of nervous tissue is as yet but little understood. The corpuscles and the nerve centers are albuminous in their nature. In the nerve fibre the axis cylinder is alkaline and albuminoid while the white substance of Schwann yields cholesterin, fatty substances and neurokeratin. Hence in the gray matter, that is the nerve corpuscles with nerve fibres consisting of the axis cylinder only, the proportion of albuminous matter is much greater than in the white matter, that is, the axis cylinder with the white substance of Schwann. In this latter fatty substances preponderate. The primitive sheath or neurilemma seems to be similar in nature to elastic substance. The chemical changes that take place in nerves during the passage of a nerve current are not known. It is said that a small proportion of heat has been detected during activity. The specific gravity of gray matter varies from 1,029 to 1,038 and that of white matter from 1,038 to 1,043, indicating that the white matter contains less water. the amount varying in different parts of the brain and nervous system. Bernhardt found in the sympathetic 64 per cent, in the cervical spinal cord 73 per cent, in the medulla 74 per cent and in the cortex cerebri 86 per cent. The albuminous matter in the nerve cells and axis cylinder is not myosin as it is not soluble in a ten per cent solution of NaCl. The nerve fibres have been found by a process of artificial digestion to contain neuro-keratin a substance found in a layer immediately around the axis cylinder and chiefly in the Schwann sheath. Both nerve cells and axis cylinders contain albuminous matter; the white substance is found be tween two layers of keratin; in the medullated fibres of the central system. although they have not the sheath of Schwann they have the keratin layer around the axis cylinder. In the axis cylinder there is also lecithin and cholesterin. Nerve cells and fibres manifest the presence of phosphorus, the fresh gray matter having yielded .49 and the white matter .89 per cent. Gray matter in reaction is slightly acid, after death the acidity becoming more marked. White substance on the other hand is neutral and at or after death becomes alkaline. The substances so far found in connection with nervous tissue are complicated in their chemical characteristics. In the ganglion cells there is found nuclein and this long with the albumin found in the nerve cells indicates the presence of phosphorus, this neuclein found in cells forming the basis of the reproductive power of the cells.

(3) Vital properties. The two vital properties associated with nerve tissue are those of nutrition and reproduction. Like the corpuscles of muscles and other tissues the nerve cells or corpuscles existing in the nerve centers receive their supply of nutriment and O directly from the circulating blood. The nerve fibres are also said to be nourished by the blood through the nodes of Ranvier. Whether this is correct is not known but it is certain that the nutriment of the nerve fibres depends in a very marked degree on their connection with certain nerve centers called trophic centers. If the sciatic nerve is cut through it will be found that the portion separated from the spinal cord may soon begin to lose its irritability, the loss of irritability beginning at the cut end and passing gradually down the nerve. This loss of sensibility according to which the change in irritability progresses centrifugally along the motor nerve is known as the Ritter-Valli Law. Fatty degeneration with the breaking up of the axis cylinder follows and the changes follow the same course as the loss of irritability, namely, from the cut end of the separated portion they pass along the nerve even to its finest branches. This is the law of

Waller. Opposed to this is the fact that the portion of the nerve remaining in connection with the spinal cord is not affected, except from the place of section to the first Ranvier node where similar changes to those already described take place. The difference is very marked and the explanation is that the one portion of the nerve has been separated from while the other has remained in connection with its trophic center. Remembering that the trophic nerve centers of the motor fibres are in the cord and those of the sensory fibres in the ganglia of the posterior root the following actions may be understood. In section of the anterior root the part in connection with the cord remains unchanged, while the separated part and the motor fibres in the nerve trunk degenerate. In section of the posterior root between the ganglion and the cord tne partof the root in connection with the cord, separated from the ganglia, degenerates while the part in connection with the ganglia and the sensory fibres remains unchanged. In section of the nerve trunk that is outside the junction of the two roots all the fibres in the separated part of the trunk degenerate while the roots and the portion of the trunk in connection with them are unchanged. The excision of the ganglion causes the whole of the posterior root and sensory fibres in the trunk to degenerate. Some few fibres found in the posterior root seem to run into the anterior root as when the posterior root is cut outside this ganglion scattered degenerated fibres are found in the anterior root. These are called the fibres of recurrent sensibility. Thus the nerve nutrition is found to take place in connection with substances reaching the axis cylinder through the Ranvier nodes and also from the centers. In the case of degeneration the axis cylinder from the central part plays the most important part in the regenerative process which takes place by proliferation, a new axis cylinder being formed. If the cut ends of a divided nerve trunk are united new fibres will be formed in the degenerated portion. This seems to be due mainly to the elongation and division of the axis cylinder of the central part of the nerve, but some difference of opinion exists as to the exact nature of the part played by the axis cylinder in the degenerated portion and also by proliferating nuclei found on the deep surface of the primitive sheath or neurilemma.

The nerve cells are not normally present in the nerve fibres but are the normal constituents of the central system out of which the nerves are sent and in the ganglia through which the nerve fibres pass to their points of connection. Thus the nerve fibres represent the nerve cell processes. In the central system the nerves are found in the gray matter the white matter consisting mainly of nerve fibres. In the anterior roots of the spinal cord we find the efferent fibres which are elongations of the axis cylinder cell processes found embedded in the gray matter of the cord, the fibres of the posterior roots being prolongations of the cells in the spinal ganglia. There are other processes in connection with cells besides those that become the anterior and posterior fibres but these terminate in connection with the gray matter of the cord. In the gray matter we also find nerve cells whose processes begin and end in the gray matter without passing from the central system. It is here in this ramification and decussation that we find in connection with the gray matter of the spinal cord and brain the nerve centers which have their connection with the afferent and efferent fibres. In some cases the afferent fibre is directly connected with the cell whose process is an efferent fibre. In other cases the relation is indirect, other cells with their other processes intervening.

Among the cells there is established a connection by the branching terminals of the axis cylinder coming into connection with the branching processes of other cells so that there is a process connection without direct continuity.

Nerve centers may be divided into two classes, centers which receive impressions and centers that originate impressions, although the same center may at different times receive and originate such impressions. Some centers when they receive an impression have the power in some mysterious way of communicating the fact and their sensation results or the consciousness of an impression. other centers have no such power and therefore when they receive an impression there is no consciousness of the impression, no communication of the fact to the mind and therefore no sensation. For example, in the case of the irritation of the skin of the decapitated frog the nerve center in the spinal cord receives an impression but does not communicate the fact to the sensorium and therefore no sensations result. But as the result of stimulating the center by an afferent impression another impression is sent out from the center along an efferent nerve and the muscles are thus stimulated to contract. There is in such a case no sensatiou and no action of the will, the movement is involuntary and the action is spoken of as a reflex one. In regard to the center in which impressions originate some of these are stimulated by the will and are called voluntary centers while others are without voluntary influence. The term automatic although applicable to the action resulting from the activity of both of these centers is generally restricted to those on which the will has no influence, the term voluntary being limited to those which the will arouses. Nerve centers may be classified as: (1) Those which receive impressions; of these there are two kinds, (a) those that receive impressions and communicate with the sensorium, consciousness of an impression or true sensation resulting. These are the true sensory centers. (b) Those which receive impressions causing them to originate other impressions. No communication with the sensorium follows and no sensation results; hence these are called reflex centers. (2) Those that originate impressions, either (a) under the influence of the will called voluntary centers, or (b) without the influence of the will, called automatic centers. Nerve centers are sometimes classified according to the actions in which they are concerned, for example, psychic, inhibitory, etc. In the nerve centers we find a distribution of action corresponding with the division of labor. The initial action is performed by a very complex set of organs specially adapted to receive impulses or sensations from the outside. This excitation is then transmitted by means of nerve fibres to the central nervous cells which seem to perform the function of classifying, dividing, and redistributing those impulses as well as in certain cases restraining impulses so that the higher nerve cells may be free to utilize these impulses. Associated with these higher nerve cells we find those centers which can initiate impulses within themselves without external stimulation, thus possessing the capacity of initiating energy within themselves.

The functions of those centers of action may be classified as follows: (1) Reflex action. These nerve centers possess the capacity of reflecting impulses received from an afferent nerve sending the impulse by an efferent nerve to some of the active tissues. (2) Acceleration. Some centers have the power of increasing the response to a given stimulation, this augmenting power depending on the central nervous cells rather than on any

local causes. (3) Co-ordination. Reflex actions require the cooperation of several centers, for example, there are receiving cells, distributing cells and directing cells, all of these cooperating in connection with the nervous impulse. (4) Inhibition. Certain nerve cells restrain other cells or tissues either restraining the receptive power or diminishing the impulse distributed and sent on. (5) Automatic action. Certain nerve cells have the power of originating impulses without any external exciting stimulation. The best example of automatic action is found in the center controlling the respiratory movement. All or at least almost all those automatic actions are connected in some way with reflex actions. In these nerve centers we find the mental activity the functions pertaining to and discharged by these centers forming the basis of the mental acts which we classify under perception, conception, thought, memory and volition.

The psychic question is one of correct distribution in the case of these functions for the adequate development of the mental activities. The operations of the mind are related in some way to those actions which result from a long series of extrinsic and intrinsic stimulations, modified, limited and enlarged by those internal influences which are brought to bear on the nerve cells and centers, depending on activity, association, hereditary transmission and contact with the external world of sense. Often we find efferent impulses coming from the brain and spinal cord without any preceding external stimulation. The resulting movements are called automatic, these impulses arising from changes in the nerve center itself. It is claimed by some that no such changes exist but there are certainly rhythmical alterations taking place in the central nervous system, notably in the medulla which give rise to the sending out of impulses of an efferent nature which control the rhythmic action of the muscles of the thorax in respiration. The same kind of movements is undoubtedly found in connection with other rhythmic actions of the body organs. In connection with the brain we find impulses originating in connection with volition, the resulting impulses being voluntary. We do not find such voluntary activity in connection with the spinal cord. It is claimed that in the spinal ganglia the same automatic impulses originate in connection with nutrition, the nerve cells controlling the nutrition of the nerve fibres. In connection with the heart we find rhythmic action, the muscle being interspersed with ganglia so that even after removal from the body there is preserved for a time the capacity for these rhythmic movements. In a subordinate sense it is believed that these actions are automatic the ganglia sending out impulses to the muscles.

Reflex Action. A reflex action is one that takes place independently of consciousness and without any voluntary effort, the primary excitation being applied to an afferent nerve. In every reflex action there are concerned (1) an afferent nerve, (2) a nerve center or group of connected centers and (3) an efferent nerve or nerves passing to some peripheral structure, such as a muscle, gland or blood vessel. The stimulation of the skin of the decapitated frog with its resulting movements has already been referred to as an example of reflex action. The afferent impulses reach the center and the efferent impulses are given out from the center. The nerve center must not be regarded as simply transmitting the afferent and changing it into an efferent impulse for the efferent may bear no certain proportion to the absolute intensity of the afferent impulse; for example, the smallest particle of any foreign substance passing into the larynx may set up the most violent coughing of a reflex nature, the mus-

cular contractions and therefore the efferent nervous impulses being altogether out of proportion to the intensity of the stimulus and consequently to the afferent impulses. The reflex center is not to be regarded merely as a shunting station, but rather as a storehouse of latent energy which is set free and made manifest when an afferent impression reaches the center. A reflex action may be limited to a single muscle or group of muscles or it may effect many groups of muscles by diffusion of the reflex action, or muscle glands, blood vessels etc. The stimulus that arouses the reflex center may at the same time stimulate a center connected with consciousness, but in this case the movements following the activity of the reflex center are quite independent of the activity of the true sensory centers, for example, the case of mustard in the mouth. In reflex action we have (a) the primary excitation. This may take place in the nerves of general sensibility or in the nerves of the special senses. Some nerves more easily excite reflex actions than others, for example, in the case of contraction of the pupil under the influence of the light falling on the retina. The afferent nerve is the optic, the center is the corpora quadrigemina, the efferent nerve the third cranial. (b) A reflex action may follow the excitation of a sensory nerve either at its beginning or at some point in its course. In the latter case the action is less active. (c) The gray substance containing the nerve cells forms the chief part of the reflex centers and we find groups of such reflex centers connected by intermediate fibres. The power of excitation caeses if these nerve centers are isolated from the psychic centers which direct voluntary activity, for example, after decapitation reflex action takes place with more intensity than in the living animal. These reflex actions may be inhibited therefore from higher centers and this is called inhibition of reflex action. (d) Reflex action may take place in a single muscle or in a group of muscles. The muscles may be grouped according to stimulation and the degree of excitement of the reflex center. Pfluger has shown that in the case of the decapitated frog excitation of the skin of one hind leg results in transmission from the center of impulses to the muscles of the foot on the same side; by increasing the excitation it is transmitted to a center on the other side and the muscles of both hind legs contract; by a still further increase of excitation the stimulation is transmitted to the higher centers and the contraction of the front limbs results; if the stimulation is still increased the highest reflex centers may be reached and the result is general contraction of all the muscles spasmodically. (e) Sensory stimulation may result by a reflex process in motion, secretion and consciousness, for example, mustard in the mouth may produce involuntary movements, salivary secretion, and a conscious sensation. (f) The use of certain substances increases the reflex action, for example, strychnine; whereas certain substances diminish excitability, for example, potassium bromide, atropin, chloral hydrate. (g) In order to produce reflex action in certain cases a number of excitations are necessary. If the individual stimulus is weak no reflex action follows and if the individual stimuli are rapidly applied the sensation affects the center. In certain cases also reflex action is produced as a result of the action of a series of centers in which the cerebral centers control the deeper brain ganglia and those deeper ganglia control certain centers in the spinal cord. This is called the super-position of reflex actions. (h) The time occupied by these reflex actions can be approximated by measuring the time between stimulation and movement and subtracting from this total time the time neces-

sary for the stimuli to pass along the nerves and the latent period of contraction. The amount of time left will represent the period of reflex action. It is found to be .0555 to .047 of a second. It may be shortened by the chemical action of strychnine.

The afferent impulses reaching the center give rise to the sending out of impulses and no doubt can exist as to the relation of the two impulses, as in the case of the brainless frog by pricking its skin movements will result in the exterior parts of the body. Reflex actions may take place in connection with the brain and spinal cord, the resulting movements in the case of a muscle-nerve preparation depending on the strength of the stimulus and the nature of the stimulation, the resulting contraction being a measure of the strength of the stimulation, although it is subject to variation. The effect of the stimulus depends on the condition of the center and the arrangement in connection with the nervous mechanism. If a slight stimulus is applied to a delicate part of the body it may result in a violent motion, while the same stimulus on the outer surface of the body may produce hardly any result. In the case of the sensory and motor nerves there is no appreciable alteration in the strength of the impulse during the passage so that the change must take place in connection with the center. The reflex action does not mean simply that the impulse is reflected in a certain direction but that the centers have the power of modifying by increasing or diminishing the impulse so that in leaving the center it is a new impulse. The centers have been compared to a magazine of explosives ready to discharge when the connecting wire is touched. Although the analogy is not perfect it indicates that great changes take place in connection with the center. There is generally a relation between the part where the stimulation is applied and the movements resulting from the reflex, this depending in the ordinary reflex on the relation of the sensory and motor nerves. In special cases there is said to be an adjustment between the sensory and motor nerves, this adjustment taking place in a complicated way through the center. The spinal ganglia do not act as reflex centers, the cells simply regulating and carrying on the trophic influences in connection with the nerve fibres. In connection with the sympathetic ganglia some claim that they act reflexly but if so it is only in a subordinate sense, some of the impulses from higher centers being possibly stored up in connection with these ganglia. The stimulation may originate in the nerves of special or general sensibility some nerves being more easily excited than others.

Inhibitory Action.—In the case of the decapitated frog the nerve centers in the spinal cord are aroused to activity and nervous impulses reach them along afferent fibres. The nerve centers previous to this reception of impulses were in a state of repose, for until they were thus stimulated no movements of the limbs were observable. It may happen however that afferent impressions may reach the centers while in a state of activity, efferent impulses passing from these centers at intervals and producing more or less rhythmical movements as the result of the alternate contraction and relaxation of muscular fibres stimulated by these impressions. When this occurs the activity of these active nerve centers may be modified by the impressions that reach them. In the first place their activity may be increased and the nerve fibres which convey these impressions that have this result are spoken of as accelerating fibres. On the other hand the activity of the active nerve center may be diminished or altogether suspended, such an effect being an inhibitory action and the

nerve fibres along which the impressions that lessen the activity of a working nerve center pass are called inhibitory fibres. These impressions in some cases originate from nerve centers, that is, one nerve center may originate an impression that restrains the activity of another center. Hence the originating center may be called an inhibitory center. An example of this inhibitory action occurs in connection with respiration. This process is due to the alternate contraction and relaxation of certain muscles under the influence of the rhythmic nervous impressions emanating from a center situated in the medulla. Certain nerve fibres in the superior branch of the vagus nerve are associated with this center and on the stimulation of these the activity of the center is diminished or suspended and the respiratory movements are slowed or altogether stopped. The impression conveyed by the nerve fibres has inhibited the activity of the respiratory centers. The nerve fibres that constitute the anterior roots of the spinal cord are efferent but not all motor, because all the fibres do not bear impulses that result in muscular contractions. There is a distribution of these fibres to the glands in connection with which the epithelial cells are induced to secretory activity. Others are distributed to the muscles of various organs, such as the heart whose activity is diminished by the impulses passing along the fibres to them. Hence by stimulating the vagus with sufficient strength the heart may cease to beat, on account of the stoppage of contraction entirely in the cardiac muscle, all the muscle fibres being perfectly relaxed; if the stimulation is feebler the heart rhythm is not stopped but is lessened. This represents the inhibitory action of nerve fibres. These inhibitory fibres it is claimed go to all the different parts of the body so that wherever there is a liberation of energy there may be a restraint exercised over the liberation in connection with the inhibitory fibres. In opposition to inhibition there is an augmentory action that may be exercised in the same way as the inhibitory in connection with the liberation of energy, so that instead of retarding the liberation there is an acceleration of it. In addition to these there are certain nerve fibres the stimulation of which produces contraction, the vaso constrictor fibres, of the blood vessels with which they are connected; the stimulation of other nerves produces a dilatation of the blood vessels, vaso-dilator fibres. These latter are supposed to produce the dilatation result by inhibitory action and the former to produce constriction by motor action. Other examples are found in the slowing of the heart's action when the vagus is stimulated.

From the standpoint of function the nerves may be divided into motor, sensitive, vascular, secretory and inhibitory. A motor nerve is composed entirely of fibres that excite to muscular action and as the impulses pass from the central system they are called efferent. Nerves which on stimulation produce sensations are called sensitive. In some cases there is a combination of both of thes ekinds of fibres, sensory and motor. The newer classification is based on a more distinct differentiation of function. Classification is sometimes made on the basis of origin and course into cerebro-spinal and sympathetic; according to their structure, medullated and non-medullated; according to their origin and distribution into somatic and splanchnic; on the basis of function generally into afferent and efferent. On the basis of the latter division we have a number of subdivisions according to the impulses conveyed along the fibres and the purpose served by these impulses. The interchange between the cerebro-spinal and sympathetic systems is through the rami

communicantes, the cerebro-spinal receiving gray fibres from the sympathetic and the sympathetic white fibres from the cerebro-spinal. The centers of the sympathetic fibres are in the spinal axis and not in the sympathetic ganglia. The size of the fibres determines to a certain extent their functions, the largest being those sent to the skeletal muscles as motor fibres, the sensory fibres being generally smaller. The vaso-motor fibres are small, the vaso-inhibitory being medullated and the vaso-acceleratory non-medullated.

In the medullated fibres we find the axis cylinder surrounded by a medullary sheath of myelin, the whole being inclosed in the primitive sheath or neurilemma. The axis cylinder is the essential and continuous part. The medullary sheath consists of a series of segmentary fibres of fatty substance united at the nodes, each internodal part forming a segment or cell with a single nucleus. The neurilemma is a fine membrane sheath enclosing the ~~the~~ nerve substance, outside of which there is a second sheath which encases isolated nerve fibres, called Henle's sheath, the continuation of the connective tissue which connects the nerve fibres in bundles. In the non-medullated we have simply the axis cylinder surrounded by the neurilemma supposed to represent the embryonic nerve condition, continuing to exist in adult life in the visceral regions in connection with the unstriped muscles. All the efferent nerves are not motor hence the term efferent is taken as the wider and more generic. Similarly all afferent nerves are not sensory in the strict sense, because sensory impulses technically apply only to those that arouse consciousness, for example, the heart action and the visceral action are not normally aroused in consciousness although in pathological conditions we do become conscious of their action. In regard to the distribution of these nerves the cerebro-spinal nerves are generally distributed to the voluntary muscles and the cutaneous surfaces, while the the sympathetic nerves are distributed to the visceral organs and the blood vessels.

The nerve fibres may be most conveniently classified as follows. I. Centrifugal or efferent nerves, carrying impulses outwards from some nerve center. Of these there are six subdivisions. (1) Motor, some times called true efferent nerves passing to muscles and causing contraction, for example, musculo-motor, pilo-motor, broncho-motor, viscero-motor, vasculo-motor and cardio-accelerator. (2) Secretory, passing to the cells of glands influencing secretion, some say causing secretion, at least a special kind of secretion, secreto-motor. (5) Vaso-motor passing to the walls of the blood vessels, influencing their callibre, these are either vaso-constrictor, causing contraction, or vaso-dilator (vaso-inhibitory) causing dilatation. (4) True inhibitory nerves, influencing other centers of nerve activity so as to neutralize or at least moderate their actions, vaso-inhibitory, cardio-inhibitory and viscero-inhibitory. (5) Thermogenic and tropihc nerves that pass to all the tissues in connection wit hheat and nutrition. Some include among these pathic nerves which are associated with sensations of pain. (6) Electrical nerves, so affecting a particular organ as to produce electrical discharges, as in the case of the electric fishes, electro-motor. II. Centripetal or afferent nerves, carrying influences inwards to the nerve centers. These are [1] the true sensory nerves, producing more or less acute sensations; [a] either general and vague, carrying to nerve centers in the brain impulses that produce sensations which are hardly perceptibie to consciousness and not of a permanent character, for example, impulses from the lungs, heart stomach,

tactile, muscular and temperature sensations; or [b] special and distinct, carrying impulses to the brain centers which give rise to sensation associated with the special senses and limited to the special organs of sense. [2] Afferent reflex-sensory, passing to the centers and conveying the stimulations which do not necessarily cause sensations and which may or may not be followed by motions, secretions, changes in the calibre of the vessels and visceral changes. [3] Inhibitory passing to centers whose activity they restrain, depressor. [4] Connecting nerve fibres which pass from the cerebro-spinal to the sympathetic system as rami communicantes and also the nerve fibres connecting nerve cells in the large nerve centers.

The peripheral extremities of the nerve fibres terminate, at least in many cases, in some special structures which are spoken of collectively as end organs, for example, end plates in muscles, the rods and cones in the retina, etc. It is probable that in normal conditions it is always through these that the nerves act or is acted upon. They are not to be regarded as structures that simply transmit the stimulus to or from the nerve but rather as storehouses of various forms of energy which is liberated on stimulation and which in the case of afferent nerves causes the stimulation of the nerve and in the case of efferent nerves the contraction of the muscles. Thus light will not directly stimulate the fibres of the optic nerve, it will only act on that nerve through the rods and cones of the retina in which it produces certain changes. It is these changes that stimulate the nerve fibres. The chief function of the efferent nerves is voluntary muscle movement. We have no evidence of peripheral voluntary inhibition, the inhibition taking place at the centers. The involuntary motivity is found in connection with the muscle of the arteries and the glands of secretion, the only voluntary influence upon these being secured by voluntary stimulation at the periphery affecting them reflexly. Vaso-constriction is motor and vaso-dilatation inhibitory in action, but whether this takes place at the periphery or in the center is unknown. In connection with intestinal movements the stimulation of the vagus produces increased action and of the splanchnics diminished action but these may be modified by other circumstances. In regard to the secreto-motor fibres to the glands we find two classes of fibres those that increase the water discharge and those increasing the secretory discharge, the latter being called trophic because of their relation to the nutrition and activity of the gland cells. Voluntary muscle inhibition takes place in connection with the centers although it does not take place voluntarlly but under stimulation from the periphery.

In regard to the afferent nerves they may be classified according to their functions, optic, olfactory, etc. It is claimed that there are thermic and pathic nerves in connection with heat and pain but the latter seem to have no proof, pain arising simply in connection with excessive sensory stimulation. It is well to remember that there is a distinction between the pure sensory and general sensory which does not affect consciousness. The afferent nerves are really either motor or inhibitory in their effects having the power to stimulate and also to depress in connection with different parts of the nervous mechanism. This it is claimed forms the basis of hypnosis.

The nerve function is discovered in connection with observations of changes following its division or stimulation. When division takes place in the case of a motor nerve paralysis follows in the muscles, while in the

sensory nerves there is a stoppage of the sensory impulses giving rise to sensations. In the case of nerves that are constantly active they are said to have a tonic effect, as in the case of the pneumogastric to the heart, while others are simply occasionally active as the depressor nerve. By dividing a tonic nerve the tonic influence is cut off at once, as by division of the vagus the heart is accelerated. In the case of occasionally active nerves when divided their stimulation indicates their function. In the case of a sensory nerve when divided the stimulation of its central end results in sensations aroused in consciousness and this forms the basis of what is called the first principle of nervous action, namely the law of specific nerve energy. Another principle is that of isolated conductivity, the nerve fibres forming continuous paths isolated from one another so that radiation to adjacent fibres is impossible. The order of changes in the case of a divided nerve is, [1] paralytic condition of the nerve cell or of the muscle in the case of sensory or motor nerves; [2] lessened irritability coming on slowly and becoming complete in a few days; [3] degeneration of the nerve peripherally, taking place gradually; (4) regeneration which takes place slowly; [5] restored function of motivity or sensibility. The exact time represented by these changes varies considerably under different conditions. Experiments indicate that degeneration and consequent regeneration require months to complete the process.

In regard to the trophic action in connection with the nerves, the question arises whether direct trophic influences are sent out from the center tothe nerve fibres or whether these changes take place in connection with changes in the blood vessels. It is well known that the nutrition of the motor spinal nerves is in connection with the gray matter of the spinal cord and that of sensory nerves in connection with the spinal ganglia. But the question is, do the nerves convey impulses that modify or check peripheral nutrition independent of changes in connection with the blood? It is claimed that after division of the cervical sympathetic there is increased growth of the rabbit's ear, after the division of the facial nerve greater development of the maxillary bones and after the division of the sciatic nerve the wasting of the extremity; but all of these seem capable of explanation on other grounds. It is claimed that by division of the fifth nerve there is inflammation of the eye, ulceration of the cornea and finally a total loss of the eye-ball, involving the disturbance of the trophic influences. It is objected however that when the nerve is divided sensibility is lost in the cornea and conjunctiva so that foreign substances lodging in the eye-ball produce inflammation externally. In support of this it is said that if the eye is protected it can be kept a much longer time from disintegration, so that these results do not prove the trophic value of the nerves. It is claimed that in paralyzed parts of the body nutrition is interrupted and therefore we have the basis for bed-sores. A similar condition is found in herpes but in neither case do we know that these results follow the lack of nutrition. Without doubt the nerve cell and fibre constitute a unity but whether this extends to the peripheral tissues is not so easily decided. It is true that muscles, the motor fibres of which have been divided manifest what is called the reaction of degeneration when stimulated electrically. In the case of the induced current the muscles are less irritable than normal and in the case of a constant current more irritable although the contraction is very slow and lengthened compared with the normal. This degenerative reaction however is only found in paralyzed muscles in case the lesion is found below the level of

the cells in the anterior horn out of which the motor nerves spring and this principle is of value in the diagnosis of paralysis. This principle has been extended to all tissues so that all tissues are said to be supplied by trophic nerves. A case is cited in which the third and fifth nerves were paralyzed. The eye continued to be protected by the contraction of the orbicularis oculi in connection with the seventh nerve, the paralysis of the third permitting further protection by the drooping of the eye-lid. The eye continued perfect for several months until the tumor that paralyzed the third and fifth also paralyzed the seventh with the result that inflammation set in and the eye was completely lost. The conclusion does not seem certain that general trophic fibres exist in the case of all peripheral tissues of the body as the changes found in supposed cases are to be accounted for on the basis of profound vascular and other changes.

At the peripheral termination of the nerve fibres we find important modifications of the structures and arrangement of the fibres. The minute branches on entering the tissues divide and subdivide very quickly, these minute divisions uniting in the formation of plexuses out of which are sent the minute processes that are distributed among the tissues. In connection with the skin we find the superficial and the deep plexuses, the former being more closely united and consisting of very small bundles. The terminal plexus represents the finest fibres. In connection with the terminal plexus the nerve fibres are again divided into branches, the axis cylinder dividing into secondary axis cylinders. Reichert estimating that in the frog's muscle one primitive fibre is divided into thirty terminal fibres. As the nerve fibre reaches its peripheral terminal it loses its medullation, the bfire consisting only of the axis cylinder which at the extreme limit of the terminal may be found to consist of minute fibrillae bound together. In connection with the sensitive nerves we find the terminal in connection with the Pacinian bodies of the skin and the end bulbs of the conjunctiva most clearly demonstrated. They are found to consist of an ovoid mass encased in capsular bodies which represent elongations of the sheath of the nerve that runs into them or of the Henle sheath. Inside there is found a semi-fluid interstitial substance in connection with which the terminal nerve fibre ends either by elongation into the terminal bulbs or by the diffusion of the fibres into the substance. The end bulbs of the conjunction are similar to the Pacinian bodies although they are much smaller in size having only a single encasing capsule, while the Pacinian bodies have several concentric capsules, formed out of the lamellated neural sheath. The nerve loses its medulla and enters the bulb as an axis cylinder, running through the bulb and turning around it, then disappearing by diffusion. In the muscles the striped muscle fibre is furnished with a single nerve process which passes through the sacolemma, dividing into branches which come into contact with the interior of the striated fibre, so that the normal stimulation is carried to the contractile substance at different points. When the nerve fibre reaches the point where it is attached to the fibre the Henle sheath comes to be continuous with the sarcolemma; it also loses the medullary part so that inside the sarcolemma it is simply an axis cylinder dividing up and branching in connection with the light colored granular matter. In connection with the nerves we find accessory elements of connective tissue, blood vessels and lymphatics. The nerve fibres are bound together primitively in connection with the Henle sheath a membrane of finely granular matter with granular nuclei. This sheath begins where

the fibres leave the white substance of the nerve centers and extends to the terminals except in connection with the ganglia. The blood vessels do not pierce through it but the minute capillaries branch in its substance. Different nerves possess different proportions of fibrous tissue, in the bony cavities being very little while in connection with the muscles the nerves have large quantities of this tissue surrounding them projecting portions being sent into the interior of the fibres. This fibrous tissue consists chiefly of white non-elastic tissue, with elastic fibres, adipose tissue and a free anastomosis of arteries and veins. The nerves are not very freely supplied with blood vessels, the arterial system being found in connection with a large number of delicate capillaries surrounding the bundles of fibres without passing through the Henle sheath. The veins are more numerous and follow the arteries. In connection with the connective tissue of the sheaths there are found lymphatic spaces which provide for free lymph circulation.

Very little is known of the metabolism of nerve tissue. The extractives derived from nerve tissue such as xanthin, kreatin, lactic acid, are elements of decomposition. We do not know whether there is any interchange of O and CO_2 during nerve activity, although there is undoubtedly an interchange of some kind, as by compressing the blood vessels of the nerves the nerve loses to a certain extent its irritability which is restored when the circulation is restored. In the central nervous system the neural metabolism is much greater than in the nerves.

The Central Nervous System.—As we have seen there are two neural systems with different functions, (1) the Cerebro-spinal which regulates and controls the functions of the animal life; and (2) the sympathetic asssciated with the internal nutritive functions. The cerebro spinal is much greater in size and also in importance, the centers of the cerebro-spinal system forming the centers for the sympathetic action, so that the sympathetic is subordinate to the cerebro-spinal. The great centers are in the brain and spinal cord the nerves being distributed from these to the muscles and the cutaneous surfaces of the body, to the special sense organs, the beginning and ending of the intestinal canal. The central system is bi-lateral in structure and function, consisting of a double series of organic structures connected closely in connection with the median line extending over the brain and spinal cord. This connection is established by means of transverse commissures which cross from side to side and form paths of communication as well as channels of harmonious activity. The two lateral sides of the brain and spinal cord thus furnish to the two sides of the body the peripheral nervous system of sensation and motion. There is another feature of this part of the system of great importance, the decussation of its fibres. The fibres cross over the median line obliquely uniting in the different parts on the two sides and as this crossing takes place from side to side the fibres become woven and interwoven at the points of crossing at the median line. These decussations become characteristic at certain points as in the case of the optic nerves at the base of the brain and the anterior pyramids in the medulla. This decussation may be either perfect or imperfect so that some fibres instead of crossing from one side to the other come from the same side on which they leave the cord. In general the nerve fibres emanating from the left side originate on the right side and vice versa. In the spinal cord we find a cylindrical mass of nervous tissue reaching from the point where it leaves the brain to its termination. It is imperfectly divided

into two halves by the anterior and posterior median fissures. The internal part of the cord is found to consist of gray substance in the form of two concave masses, the concave surface extending outwards. These represent prolonged bands of gray matter on each side of the cord connected together by transverse bands of gray matter called the gray commissure, in the central part of which is the central canal about two-tenths of a mm. in diameter. The anterior and posterior parts of the gray matter on each side of the cord are called the anterior and posterior cornua. Directly in front of the gray matter is the white commissure. Emerging from the cord at regular intervals are the symmetrical pairs of spinal nerves which pass to the peripheral muscles and the cutaneous surfaces. In the lower cervical region and the sacral region we find larger spinal nerves to the arms and legs at the points of the cervical and lumbar enlargements. On each lateral side of the cord we find a posterior and anterior root, the former arising in the posterior horn of gray matter and the latter opposite the anterior horn of gray matter. On each lateral side of the cord the white substance is divided into three columns, the anterior, lateral and posterior, running longitudinally.

In the brain we find the continuation upwards of the cerebro-spinal mass forming the encephalon within the cranial cavity. It consists of various portions of gray matter united together and connected with the spinal cord by transverse, longitudinal and oblique paths of nerve fibres. In the human subject the cerebrum represents the most perfect development predominating over the lower parts of the brain. Looked at from above the cerebral hemispheres with their convolutions alone are visible. covering over even the posterior part of the brain with the exception of the cerebellum. The lower parts of the brain which lie under and behind the cerebral mantle form a series of connected nerve structures, forming centers with associating tracts of nerve fibres. On the entrance of the spinal cord into the cranial cavity it is enlarged into the medulla, the gray matter of the cord falling backward and developing a continuous posterior layer. The posterior columns of white substance in the cord separate as they leave the cord forming at an angle with each other the fourth ventrical, passing onward and continuing the cerebellar crura. forming the restiform bodies of the medulla. Anteriorly the medulla exhibits two elevations of white matter one on each side of the median line called the anterior pyramids. In the lower parts they decussate so that the anterior pyramid on the right side is made up of fibres coming from the left side of the cord and the anterior pyramid on the left side of fibres from the right side of the cord. Just outside of the pyramids we find the two oval shaped bodies which are made up internally of gray matter and externally of white matter. At the upper extremity of the medulla is the ring-like tuberosity at the base of the brain, passing over from the one side to the other being found transverse fibres in connection with the cerebellum. As these transverse fibres cross they form the pons Varolii and laterally where they return they constitute the middle cerebellar peduncles. In the deeper portions of this tuberosity are found longitudinal white substance paths that make their way from the medulla to the cerebellum. Continuing the anterior pyramids anteriorly and the other medullary longitudinal fibres which pass through the tuberosity are bundles of fibres which come from the upper extremity as the two crura cerebri. Posteriorly they are united by the longitudinal fibres that come from the cerebellum forming the path between the cerebellum and cerebrum, the

peduncles passing to the base of the brain and uniting it with the spinal cord. The gray substance around the canal of the spinal cord expands into a surface layer in connection with the floor of the fourth ventricle, passing around the Sylvian aqueduct along the sides of the third ventricle to their terminal in the infundibulum or mass of gray matter attached to the pituitary gland, This gray substance forms the basic origin of all the nerve fibres of sensibility and voluntary movements. Close to the upper extremity we find larger masses of gray matter, chiefly the cerebellum, while in its expansion upward it forms the cerebrum, constituting the basal ganglia and the cerebral convolutions. The two cerebral convolutions are united by a broad white commissure, the corpus callosum, which covers over the lateral ventricles and the basal ganglia. The two lateral hemispheres of the cerebellum are connected together by the pons Varolii.

Continuing the columns of the cord we find the longitudinal cerebrospinal axis; passing through the ring-like tuberosity in connection with the crura cerebri they are brought into connection with the gray matter at the basal ganglia. Passing through these ganglia they form the internal capsule from which they become diffused on either side forming the corona radiata, the fibres of which become again diffused until they terminate in the gray matter of the cerebral gyri. These fibres are not continuous all the way through the brain, one set of fibres terminating in the gray matter of one region another set originating close to these and passing to another region of the brain. In this way impulses passing along these longitudinal tracts are intercepted by gray matter, changes taking place in the nerve cells before transmission to the longitudinal tracts. In connection with the sensory and motor impulses there are three longitudinal tracts, represented by (1) the nerve fibres between the periphery and the gray matter of the cord; (2) the columns of the spinal cord and the peduncles of the cerebrum uniting the gray matter of the cord and the basal ganglia; (3) the diverging fibres of the corona radiata uniting the basal ganglia with the cerebral convolutions. In connection with the passage of impulses along these tracts there are at least three nervous masses of gray substance, (1) the cerebral convolutions, (2) the cerebral ganglia, and (3) the gray matter of the cord, representing three successive centers both inward and outward for the transmission of impulses. In connection with these centers the modification of impulses may take place. Also in connection with these successive centers transformation of sensory into motor impulses may take place, so that reflex action may take place at these three successive points in the nervous system. In this way we can distinguish three grades of reflex action, (1) those taking place through the gray matter in the cord without calling in the aid of the higher centers and therefore without consciousness; (2) the reflex may take place in connection with the cerebral basal ganglia and (3) in connection with the cerebral hemispheres, so that the sensory and motor impulses will travel along the entire nerve route both inward and outward. Thus we are able to trace the passage of impulses along the entire course of the central nervous system to the cerebral hemispheres, so that impulses become conscious sensations and are transformed into voluntary ideas which when sent out along the motor paths become translated into voluntary activities.

SECTION VII. Thermal, Chemical, and Electric Phenomena of Muscle and Nerve.

THERMAL.—There is a liberation of mechanical energy from the body only when it imparts to other bodies some of its energy. The most of the liberated energy passes from the body in the or of heat, only a very small proportion of the energy being converted into mechanical energy even when the body is exercised very freely. Even during the exercise of the body the heat production is greatly increased so that exercise raises the body temperature. It is difficult to find out the relation existing between the heat production and the contraction of the muscles. Most of the experiments have been made in connection with the cold blooded animals and excised muscles. Helmholtz in experimenting on the frog found that in two minutes the muscle temperature was raised .14 to .18 of a degree C. Fick claims that in the case of a fresh muscle enough heat is produced by a single contraction to rasie three milligrams of water 1 degree C. The thermopile that is used to find out the small heat variations consists of bands of two different metals, joined at the ends so as to form a series of thermo-electric connections. By producing a difference of temperature at two of these connections there is developed a difference of potential which produces an electric current that can be measured in connection with the galvanometer. The most common metals used are bismuth and antimony. As the chemical changes in connection with the muscle become greater the amount of energy liberated increases. Similarly an increase of tension produces an increase of heat production and as the muscle contracts there is an increase of temperature. By putting the thermometer into the muscle it is found that there is a rise in temperature when the muscle becomes active, particularly if the activity is prolonged. By the use of the thermopile the slightest changes of temperature produced by a few single contractions and even by a single contraction can be estimated. Another method used is in connection with the bolometer in which the resistance is measured in connection with a fine wire put into the tissues. In the case of a frog's muscle it is calculated that the heat given off from the muscles of the thigh at a single contraction amounts to three milligrams of water at one degree C. This however is only an approximation to the amount of heat given off in connection with contraction. This heat liberation arises in connection with the chemical changes taking place in the muscle, these changes being mostly oxidation changes such as we have found in connection with muscle metabolism. There is no direct relation between the amount of materials used up by the muscle and the amount of heat produced as is the case in the steam engine so that the analogy is not complete. There is in the living muscle always the element of living substance which requires to be taken account of as part of the living material is exhausted in the process of chemical change. What change takes place in contraction is not known, whether it is the substance within the the fibre that yields rather than the fibre itself to the chemical changes. In the former case if the substance is composed of C and H then the chemical change will not involve any N waste, the results of the changes being found in the contraction and the waste assuming the form of CO_2 and lactic acid. If this view is correct then the muscle fibre itself does not pass through any change in connection with heat production but simply forms the fibre substance.

Isometric [illegible]

[illegible]

The ratio of work to heat varies considerably in the muscles depending on the muscle condition and the circumstances in which the muscle is found at the particular time, the variation being from about one-fifth to one-twenty fifth that assumes the form of work, the balance being expended as heat. In this variation we find the self-controlling power of the muscle so that even when the resistance is increased the amount of energy developed is also increased within the limits imposed by the body mechanism. The emission of heat from the muscle does not take place only when the muscle is contracting, the muscle being engaged in this heat generating process even in rest, so that the heat production during contraction is simply the enlargement of the function normally performed by muscle continuously. Heidenhain has found by the use of a delicate thermopile in the case of a single contraction in a frog's muscle a variation of .001 to .005 which would represent a production of 1-1,000th to 5-1,000th of a calorie per gram of muscle. According to Fick this is modified to the extent that the maximal production is 3-1,000ths of a Ca. to the gram of muscle. When work is done by a muscle there is an amount of energy deducted from its total capacity but this does not mean that as the muscle increases in activity the heat production is diminished, because within definite limits the heat production is increased. As soon as a muscle is stretched there is an increase of metabolism and associated with this is an increased heat production. If the muscle is tense when contraction takes place then there is an increase of heat production and the heat is increased if the muscle is so stretched that it can not contract when the stimulus is applied to the muscle. Greater heat production takes place when the muscle is contracted under isometric than under isotonic conditions. If a muscle is stimulated to its maximum of contraction and is made to do work with increasing weight then there is an increase in the amount of work done and in the heat production until a point is reached when exhaustion takes place. In the case of a muscle artificially cooled or poisoned with veratrin the change takes place largely during relaxation. As we saw the relaxation of the muscle does not simply represent a passive recoil but implies physiological activity and as a result there is a heat production during the relaxation as well as during the contraction. By permitting a muscle to contract without doing any work and loading it at the top of the contraction so that the load rests on it only during relaxation there is an increased heat production and as the weight increases in size the heat production also increases. Fick took a muscle permitting it to raise a weight and (1) he allowed the weight to remain during relaxation; (2) he allowed the muscle to relax without the weight. He found in the former case that greater heat was produced than in the latter case and concluded that if a muscle is working an amount of energy is deducted from that which would without the work appear in the heat. But the fact that during relaxation the muscle was loaded made a difference the load producing an increased heat production. In connection with the cardiac muscle there is heat evolution as the heart according to Marey is warmer during every systole. In an ordinary muscle if the muscle bears a weight that produces extension during rest there is no transference of work beyond the muscle, and all the chemical change transfers the energy into heat. Here the heat production corresponds with the amount of work done until the maximum is reached. If when the muscle contraction has reached its highest point the weight is taken off then there is work done by the muscle outside the

muscle and the heat production is lessened. According to Heidenhain where the muscle performs its work in connection with a number of smaller contractions as compared with a fewer number of larger contractions, then in the former case the amount of heat produced is smaller than in the latter case. This is due to the increased metabolism in the case of the larger contractions. This is practically illustrated in ascending a gradually sloping as compared with a steep hill; in the former case the exhaustion is less rapid than in the latter.

In the case of a muscle if it contracts continuously and at the same time performs work there is a greater heat production than when the muscle is in tetanus. In the tetanic condition there is an opposition of muscles with high temperatures. It has been found that if dogs are kept in a tetanic condition by stimulating them electrically then death results from the increase of temperature to a point beyond which life is impossible. As the increase in heat production advances the muscles become fatigued and this over-fatigued condition makes the animal less capable of resisting the degenerative changes. If there is a free blood supply then the heat production is more active and recovery is more rapid if there is a free blood circulation. It is found therefore all other things being equal that in the contraction of a stretched muscle more heat is evolved than in the case of an unstretched muscle; and when a muscle contracts without doing any mechanical work more heat is evolved than in the case of a muscle contracting and at the same time doing work. These points are very important indicating that the muscle is not simply an engine to do a certain amount of work but that the development of energy is dependent upon the conditions and relations of the muscles. In the case of a muscle in relation to the opposing muscles and in its own muscular relations it is found that a greater amount of work can be done. We have here also the principle of the conservation of force so that if all the energy liberated takes the form of heat then there is a greater amount of heat than if part of the energy is devoted to mechanical work. Hence the greatest amount of direct heat production takes place in the tetanization of the muscle when no work can be done. In connection with this it is not to be taken for granted that when a muscle is doing a greater amount of work. for example, in lifting a weight under tension, that the mechanical work is done at the expense of heat energy for there is an increase of both heat energy and work energy. Even when the muscles are in a condition of rest the muscle heat is greater than that of the arterial blood so that when contraction takes place there is a still further increase of heat. Chauveau observed the heat conditions in the levator labii superioris in the horse finding that during voluntary contraction there was the liberation of 300 milicalories per gram per minute. In connection with the normal use of the muscles there is found an increase of temperature although this is not due solely to the muscle contraction, it is partly if not largely due to the plentiful blood supply circulating in connection with the muscles in activity. The thermal phenomena of muscles may be summarized. (a) in muscle contraction there is a heat generation; (b) where the muscle contraction is interrupted there is a greater heat production than where the contraction is steady; (c) a muscle working produces less heat than a muscle doing no mechanical work; (d) as the tension increases in connection with the muscle the heat evolution also increases; (e) the fatigued condition of the muscle produces a decrease in the heat producing power.

CHEMICAL PHENOMENA OF MUSCLE IN ACTIVITY AND IN RIGOR.—In

muscle we find about 75 percent of water and about 25 percent of solid matter, of which about 21 percent is proteid and 4 fats, extractives and salts. It is very difficult to determine the chemistry of living muscle because of the instability of the chemical combinations which lie at the basis of changes taking place in the muscle. In the attempt to analyze the chemical conditions such alterations take place as produce an abnormal or death condition. The chemical changes that take place during contraction are not settled among physiologists, but the following are accepted; (a) the amount of O used by the muscle is increased; (b) the amount of CO_2 is more than proportionally increased; (c) the amount of N waste is not increased; (d) the muscle becomes acid in reaction, sarcolactic acid being found: (e) Gaseous extractives are diminished while alcohol extractives are increased. One explanation of this is, that the muscle contains certain carbonaceous matters which when the muscle is acting acts as a fuel, being oxidized by the O in the blood, the results being movements and heat. It is not the albuminoid matter of the muscle substance that is used up but the carbonaceous material found in the muscle hence while there is no increase in nitrogenous waste there is an increase in carbonaceous waste. One of the products of this chemical change is the sarcolactic acid formed from the carbonaceous materials lodged in the muscle. It is a question whether this explanation is sufficient to account for the changes that take place. It may be noted that the increased production of CO_2 is not accounted for by the oxidation of carbonaceous materials by the O of the blood, for although it is true that more O is used by the muscles when working, it is also true that the increased proportion of CO_2 is much greater than can be accounted for by the increased consumption of O. In addition to this a living muscle placed in an atmosphere free from O will continue to produce CO_2 as long as it is living. As muscle itself contains no free O and the surrounding atmosphere is destitute of this gas it is clear that CO_2 cannot be the result of the direct oxidation of carbonaceous matter present in the muscle, but must be a result of the splitting up of some bodies which contain CO_2. It may also be said that whether the acid reaction of the muscle that has been actively working is due to sarcolactic acid or not, it is certainly not due to the CO_2, for the red dye on the blue litmus which it produces is permanent. One result of this chemical activity is the increased production of heat. This is shown by the fact that blood flowing from a contracted muscle is warmer than that from a resting muscle. The same fact can be proven by putting the bulb of the thermometer into a muscle and causing contraction when the mercury will be seen to rise. Like all other living corpuscles muscle is at all times the seat of chemical changes and it is thus constantly the source of heat. As the chemical changes during the contraction are more active then the amonnt of heat elaborated during that time is increased. The heat produced by any contraction is in inverse proportion to the amount of work done by the contraction.

It is difficult to distinguish chemically between dead and living tissue. The living muscle differs from the dead muscle in this fact at least that the former is soft and elastic while the latter is hard and cloggy. This difference rests on a difference in the relation of solids and liquids, the living muscle consisting of the muscle plasma and the sarcous elements, whereas in the dead muscle the plasma has become coagulated. So far as known to us there are two main differences between living muscle in a resting and in an active condition. Living muscle when resting is either

neutral or slightly alkaline in reaction, while in activity it is slightly acid, this acidity arising from the presence of sarcolactic acid. Hence the activity of muscle involves to a certain extent the same conditions as that of death and it is claimed that the analogy is even more complete, so that when the muscle becomes more fatigued and the relaxation is prolonged it is claimed that there is a semi-coagulation of the muscle plasma. Fick claims that the contraction and relaxation periods in the case of a muscle depend upon, (1) the production of lactic acid and myosin during contraction, and (2) the production of CO_2 and the dissolution of myosin during relaxation. It is difficult to prove this because we cannot tell what takes place without the death of the muscle. It is certain that accompanying muscle activity is the production of CO_2. If the gas pump is used to collect the CO_2 from the muscles in the active and resting conditions it is found that if the muscle has been resting previous to rigidity there is a greater amount of CO_2 than in the case of an active muscle. It is claimed that more glycogen is found in a resting muscle and a larger amount of sugar in the tetanized muscle. Helmholtz claims that previously resting muscle yields a larger amount of water extractives and a smaller amount of alcohol extractives. In an active muscle the CO_2 is not produced directly by oxidation but arises in the process of splitting up substances which have been combined in connection with O. In addition it is found that there is no proportionate relation between the CO_2 and the O when in artificial circulation contraction takes place.

Fresh muscle causes the red litmus to become blue and the blue to become red, this chemical change arising in connection with the phosphates. The sarcolactic acid produced in an active muscle is neutralized in connection with the sodium carbonate and the di-sodium phosphate. There is a definite diminution of glycogen during activity, while it accumulates during rest. The sarcolactic acid it is claimed by some is formed in connection with the carbohydrates especially in connection with the glycogen. In the rigor-mortis conditions sarcolactic acid is produced just as during contraction and according to Ranke there is a maximal acidity that is developed in connection with the muscle either in rigor or in contraction but this cannot be due to glycogen in the rigor condition because there is no glycogen increase. Hence it is suggested by others that sarcolactic acid is developed in connection with the proteid under fermentive action. The muscle activity in contraction therefore is only partially due to glycogen. It is found in the normal heart that out of 60 grams of solid matter only about one and one half grams represent glycogen. During a day there is produced about 300,000 Ca of heat which would require 70 grams of glycogen. Hence the accumulation of glycogen can not account for the muscular activity of the heart. Among the other carbohydrates the dextrose found in the blood must be regarded as an important element. It is estimated that 150 grams of dextrose pass through the coronary circulation daily and of this amount one half would be sufficient to produce all the cardiac heat. An estimate of proteid for the heart production of heat is 70 grams and of fat 30 grams. Hence it is claimed that to sustain the contraction force of the heart normally requires about one half its weight of solid food daily. Hence in the generation of energy it is supposed that the adaptability of the different muscles of the body renders it possible that energy may be taken from the proteid, carbohydrate and fat according to the necessities of the system so as to provide for those chemical properties that are essential to muscle con-

traction.

Rigor Mortis.—In the death of muscle it undergoes an important chemical change. All muscles, shortly after being taken from the body and in even while still in the body, soon pass after the death of the body into a condition in which irritability is lost, the loss of irritability which takes place gradually being followed by rigor mortis. This indicates the muscle death and may be said to be associated with these charactiristics; (1) muscle when living is more or less translucent while the muscle when rigid becomes opaque; (2) Muscle when living possesses the properties of extensibility and elasticity, indicated by the fact that it is easily stretched by a weight or by tension, and when the weight or tension is removed the muscle returns to its normal length. The extent of this elasticity depends upon the muscle condition so that an active muscle properly nourished returns more readily and rapidly to its normal length when extended than a fatigued muscle. In the case of the dead muscle extensibility is lost to a considerable extent and elasticity is greatly diminished, so that it requires a great force to stretch the muscle; and on removal of the weight or tension the dead muscle does not resume its normal position. (3) In the case of the living muscle it is more or less soft and diffluent while in the case of the rigid muscle it is found to be more solid and resistant (4) Associated with the approach of the rigor mortis is a shortening of the muscle which may be more or less according to circumstances. This shortening does not indicate the generation of energy because a very slight force will prevent the contraction of the muscle as it enters into the rigid condition. Muscle completely deprived of nourishment either by ligature of the blood vessels, by removal from the body or by cessation of the circulation which occurs in the case of general death passes after an interval into the condition of cadaveric rigidity. The length of time which elapses between the stoppage of the blood supply and the beginning of rigor mortis is much longer in the cold than in the warm blooded animals. In the latter also the time of the appearance of the rigidity is influenced by the circumstances under which death occurs. Often in diseases which have gradually exhausted the strength rigor-mortis soon comes on, while in the cases where death has come suddenly upon a system full of vigor its appearance is delayed. During the interval before the coming on of the rigor the muscles retain their irritability. They are still alive and will contract when stimulated. Irritability gradually lessens and it completely disappears as the muscle somewhat suddenly enters into a rigid, opaque, unelastic condition. At the same time the muscle becomes acid in reaction and a quantity of CO_2 is given off. The duration of cadaveric rigidity varies; in cases where it soon appears it rapidly disappears; while it remains longer and is more marked when some time has elapsed before its development. As it passes off the muscles become soft and diffluent, a result of putrefaction. There is of course no return of irritability, for the muscle is dead and irritability is a vital property.

The exact nature of rigor mortis is not definitely understood. It is certainly not a vital action of the muscles as it does not appear until the irritability is lost. The muscular substance or myosin becomes coagulated and this follows the cessation of the blood supply. In the human subject rigor mortis successively appears in the muscles of the jaws, neck, upper and lower limbs and it disappears from the parts in the same order. The length of the interval between general death and rigor mor-

tis varies from a few minutes to several hours or several days. The entire disappearance of irritability coincides with the complete establishment of cadaveric rigidity and this last period of from one to four days. After the cadaveric rigidity disappears when putrefaction ensues. Muscular rigidity may also be produced by heat at 40 degrees C, the muscles of the frog becoming rigid at 53 degrees C. This rigidity differs from rigor mortis as it is due to the coagulatiou of other proteids besides myosin produced by heat. Muscular rigidity may also be produced by the injection into the vessels of a two percent solution of HCl or lactic acid. This rigidity will yield to the injection of a fifteen percent solution of Ammonium Chloride. The rigor mortis is undoubtedly the result of chemical changes in connection with the muscle, the result of which is that the muscle permanently loses its vital properties. By taking a dead muscle and removing from it all the fatty, tendinous and connective tissue and placing it in such a position that all the blood can be removed from it by the use of some saline solution; if it is then cut into pieces and washed with water there will be found in connection with these washings albuminous and extractive substances. After this washing has been continued until there is no proteid reaction a large part of the muscle will still remain. By placing this in a ten percent solution of some neutral salt, like ammonium chloride, there will take place a dissolution of the muscle substance. By allowing the morė solid part to fall to the bottom and collecting it and placing it in pure water there will be found a precipitate of white matter which is called myosin. This myosin represents a proteid substance yielding to the ordinary proteid reaction. It is found to be soluble in saline solutions and is usually classed among the globulins although it is not so soluble as the paraglobulin in saline solutions. When it has been dissolved in connection with a neutral saline solution, precipitation may take place in connection with NaCl and it may be purified by the use of a saturated solution. When it is dissolved in a saline solution it may be freely coagulated by means of heat, coagulation taking place at about 56 degrees C. In this respect it differs from paraglobulin and serum albumin which are coagulated only at 75 degrees. It is analogous to fibrinogen which will coagulate at a temperature of 56 degrees. Any of the globulin family in connection with the dilute acids may be transformed into acid albumins and become indissoluble in water and in the dilute saline solutions, and only soluble iu connection with diluted acids and alkalies. By dissolving one of the globulins in diluted acid there is a chemical change taking place so that an acid albumin is formed. The same thing takes place when a globulin is dissolved in a diluted alkali, the result being the formation of an alkali albumin. Myosin can be very readily transformed into acid albumin so that by using diluted HCl the myosin may be transformed in muscle into acid albumin form and thus dissolved out of the muscle. This acid albumin which is thus formed has been called syntonin which is regarded as one of the necessary constituents of all muscle. It has been found however that the muscle contains myosin rather than syntonin, so that the syntonin simply represents the acid albumin resulting from the treatment of myosin with dilute acid. It seems from this that myosin is very similar to fibrin although the fibrin is much less soluble, the myosin forming a substance intermediate between the fibrin and the globulin.

In the case of a muscle washed out with a saline solution if it is then washed out with a solution of HCl acid other proteids may be

found in connection with the muscle, for example, gelatin and other substances found in connection with connective tissue, nuclei, etc. If the living muscle is subjected to a very low temperature and then thawed the irritability will be restored indicating that the muscle has not passed into the rigid condition. If living muscle in its contractile condition from which the blood has been washed out is subjected to a temperature below freezing point and while in this frozen condition is cut up and pounded in connection with snow and a one percent solution of NaCl there is obtained a solution which is found to be slightly opalescent, called the muscle plasma. It is found to be at first in a liquid condition but will soon pass into the gelatinous condition and then become coagulated, separating into a clot and a serum. This clot is analogous to the blood clot but unlike the blood clot it is loose and non-fibrillar. As the fluid coagulates a change will take place from an alkaline and a slightly neutral reaction to an acid reaction. The more solid part of the clot represents myosin responding to all the myosin reactions. The serum is found to contain albumin, some think serum-albumin, certainly not paraglobulin because it does not coagulate at the same temperature. To distinguish it from the other globulins it has been called myoglobulin. In addition to these the red muscle contains hæmoglobin and other coloring matter. It is generally supposed that myosin arises from the transformation of myosinogen the transformation taking place in connection with a ferment, just as fibrin is formed from fibrinogen. From what has been said it can be seen that rigor-mortis represents a coagulation of the muscle plasma differing only from the coagulation of blood in the fact that it is myosin and not fibrin that we find associated with coagulation. The rigid condition as well as the firmness of the muscle seems to be associated with the change from the liquid to the solid form. As soon as the plasma passes into the gelatinous stage the rigor-mortis condition begins to come on, followed by the condition of stiffening.

One important point of difference is noticed between the coagulation of muscle and that of the blood. As the blood coagulates the reaction change is only slight, whereas in the case of muscle becoming rigid the muscle is distinctly acid. During rest a living muscle is neutral or slightly alkaline, the latter condition existing in connection with the presence of the lymph. This acid reaction exists throughout the entire rigid muscle solid as well as liquid and is said to be associated with the myosin. The cause of this acidity is not known. The change produced in connection with the litmus paper is permanent in connection with the acid muscle; it is not the carbonic acid which produces the acid reaction because CO_2 in connection with litmus is not permanent. In connection with a muscle in the rigor-mortis condition there is found sarcolactic acid and it is claimed that the acid reaction depends upon this acid. Some claim that the acid reaction is the result of complex processes rather than being due simply to the presence of sarcolactic acid. In connection with the rigid muscle we find a development of CO_2. The muscle when living and in an irritable condition is subject to tissue respiration involving the use of O and the production of CO_2. When the arterial blood enters the muscle it gives off some of its oxygen gathering up from the muscles the CO_2 so that as it leaves the muscle it is distinctly venous. When the rigor-mortis condition sets in the CO_2 production is largely increased. The CO_2 in the living body results from oxidation processes in connection with C and substances that contain C. It has been supposed that the increase in the

production of CO_2 in the rigid muscle is due to the C of the muscle and the other elements in the muscle that contain C being given up to oxidation processes. This cannot be the case, because the increase in the CO_2 production does not involve a corresponding increase in the O consumption and it has been found that there is no free O in connection with muscle. Muscle when put in an atmosphere that does not contain free O will continue to give off CO_2 and after its death will also produce CO_2 similar to that found in the muscle existing in an atmosphere with O. This indicates that the CO_2 production cannot take place in connection with oxidation. In the rigid condition therefore there must be found some substance or substances which when broken up liberate CO_2, the formation of the CO_2 having taken place previously. Muscle when rigid becomes acid, contains a large proportion of coagulated myosin and is found to develop a large proportion of CO_2. Foster claims that the intensity of the rigidity corresponds with the acidity of the muscle and also the amount of CO_2 found in connection with it. The nature of the rigidity depends upon the amount of myosin found in connection with the muscle and the acidity depends upon the amount of lactic acid developed as well as the amount of CO_2 formed, so that these three substances may be associated with the dividing up of the same substance or substances in connection with the muscle.

In addition to the proteids that are found in connection with the muscle in the rigid condition there is found fat in the connective tissue and in the substance of the sarcolemma. It is not known what the function of these is in the living condition, much less what change takes place in the dead condition of the muscle. In the muscle we also find the carbohydrate in the form of glycogen which is a substance very similar to starch. In connection with the living muscle more or less of glycogen is always found. In the rigid condition the glycogen is transformed into some sugar form. The extractives are found in connection with the waste products that arise in connection with the muscle metabolism during life. The muscle represents the larger part of the nitrogenous proximate elements of the body and hence the nitrogenous extractives in the muscle are of considerable importance. The chief nitrogenous element is the urea with the allied uric acid so that in one of these two forms all the nitrogenous waste is thrown off from the muscle. There is not found any urea or only a very small quantity in connection with the muscle either in the living or in the rigid condition so that the urea cannot be said to represent one of the direct end products of muscle substance. In connection with the muscle there is found another extractive kreatin which is a compound substance that may be divided into urea and a methyl glycin called sarcosin. This kreatin form which contains urea may be regarded as the end product of muscle metabolism.

In ordinary circumstances when the muscle enters into the rigid condition it comes on slowly fibre after fibre being affected by the rigor. As the gradual contraction of the muscles take place they are hardened in this condition and they become solidly fixed in the rigid condition. The rigid condition of the body is usually determined in connection with the weight of the different portions of the body and the muscular contractions. The time necessary for the rigor is determined by the condition of the muscle and its temperature, a more active muscle being subject to greater chemical changes and these changes taking place more rapidly so that the rigor mortis comes on more quickly. The muscle condition very

largely determines the onset of the rigor so that in the case of vigorous muscle at the period of death the rigor comes slowly; whereas in the case of muscles enfeebled by sickness or disease or improperly nourished it comes on quickly and also passes away quickly. It is claimed by some that the contraction found associated with the muscle at the moment of death passes into the contraction of the rigor condition. Where persons die of nervous diseases particularly if the spinal cord and brain are affected the rigidity may ensue quickly. In the case of cholera where death is associated with strong muscular contractions the rigidity comes on quickly, in some cases the contractions of the death struggle passing into the contractions that represent the coming on of rigidity. In such cases as these the body does not lose its heat the chemical changes that take place in connection with the rigor preserving the body temperature. The cause of these contractions is not known although it is supposed that they arise in connection with the stimulation arising from chemical changes so that the nerve cells stimulate the muscles to activity. The muscles continue capable of responding to stimulation even after rigidity has appeared, because the process of coagulation gradually develops the muscle fibres, some remaining longer irritable than others. It is claimed by some that the nervous system sends out impulses to the muscles even after death producing changes in the muscles which assist the progress of the rigor. This it is claimed is proved by the fact that where muscles are curarized they become rigid very much more slowly. The rigor mortis in the normal warm blooded animal comes on from a few minutes to 18 or 20 hours after death and may last from one to several days. The rigid condition of the muscle may be removed by artificial movements of the parts of the body and when thus removed will not return again.

The most probable explanation of the contracted condition of the dying muscle is that it is produced by the coagulation of the fluid that is found within the sarcolemma. Kuhne has shown that such a change does take place in muscle plasma extracted from a muscle after being frozen. This coagulation results from the chemical alteration arising from the action of the myosin ferment which is one of the end products of the muscle death. Hermann claims that the contraction in the rigor mortis is of the same nature as the normal muscle contraction; when the muscle becomes exhausted or is poisoned by veratrin the prolonged contraction very closely resembles the rigor mortis in the alteration of form, the heat generation, the acid formation and the production of CO_2; in addition to this he claims that the muscles becomes rigid more rapidly if the nervous connection is intact. It seems however quite certain that the rigor contraction is very different from the normal contraction, for example, instead of coagulated myosin the normal muscle has myosinogen uncoagulated, and in the muscle contracting during rigor elasticity and extensibility are diminished, the contraction taking place slowly and continuing for a considerable time. In the production of the contraction there is a difference, the muscle continuing to contract in rigor mortis even when it has lost its irritability and when cut off from all nerve connection. The rigor condition is found equally in the voluntary and involuntary muscles, the cardiac muscle also becoming quickly rigid. When the rigor passes away there is the beginning of putrefactive changes, although it is claimed by some that even when precautions are taken to prevent decomposition the rigor mortis may pass away. As we have seen in the rigor there is a coagulation of the muscle substance, al-

though this may be prevented by a cold below zero C. Although the cold prevents coagulation this does not enable us to get the chemical analysis of muscle because as soon as we begin to divide up the muscle its living characteristics disappear. Halliburton finds that the coagulation is prevented by neutral salts, such as NaCl, so that by the use of these the properties of the muscle can be investigated. So long as the muscle is in its living condition it is taking from the blood proteids, carbohydrates, fats, salts, etc., using these in building up its own tissue substance. This substance is largely made up of proteid, albumin, myoalbumin and myosinogen being always found in muscle. In the resting condition the anabolism of muscle constantly implies the formation of waste matters: during the contracted condition these waste products are increased the result being that the muscle becomes acid in reaction. In the rigor condition there is added to the other products of ordinary contraction the transformation of myosinogen into myosin which produces muscle rigidity. The rigor mortis is essentially a coagulation although we can not tell why the myosin coagulates on the death of the muscle. Hermann claims that myosin, lactic acid and CO_2 are the products of the disintegration of some complex substance, the rigidity being simply a removable contraction. But it is found that rigor mortis does not produce any change in the doubly refractive substance which is regarded as the contractile element of muscle. It is claimed by Danilewski that myosin is found in the doubly refractive elements. In the case of thermal rigor the muscle of a frog will pass into rigor by being dipped in a saline solution at 41 degrees C, the cardiac muscle at 45 degrees and the mammalian muscle about 51 degrees. This thermal rigor is a much accelerated rigor but the moysin does not become insoluble. If muscle is raised to 75 degrees or above, there is no acid reaction, but rigor due to coagulation of the proteids and hence not a true rigor. The alcohol rigor is a similar proteid coagulation. Rigor mortis is of value in Forensic Medicine as a means of indicating the time of death. The rigor is found to come on more suddenly when persons are taken by surprise in the active work of life. Onimus gives the following order of the disappearance of irritability, left ventricle, stomach and intestines in 55 minutes; right ventricle and bladder 60 minutes; iris 105 minutes; facial and lingual muscles 180 minutes; extremity muscles and muscles of the trunk from four to six hours after which rigidity is completely established.

In connection with muscle it is important to notice the growth and atrophy of the muscle. Out of a single cell as it increases in size and becomes elongated there is developed the striped muscle fibre. A division takes place in the nucleus several times and differentiation is found in the protoplasm. In the mammalian muscle the nuclei move towards the periphery of the fibre being associated with the interspaces between the fibrillae of the fibres. The sarcolemma represents the cell membrane although some claim that it is formed out of special cells which are broadened out in the formation of a flat membrane. In the fully developed muscle we find large numbers of these fibres. By the functional use and exercise of the muscle it will become enlarged as well as strengthened this being due to the increase in the number of the muscle fibres. In this enlargement new fibres are developed, the old fibres are increased and the interstitial substance is also increased. Exercise increases the number of these fibres in connection with the nuclei that are found beneath the sarcolemma. Some muscles grow without any such exercise this be-

ing due to the energy that is native to the tissue, perhaps under the influence of the trophic nerves. The fact that blood enters a muscle does not of necessity produce growth; accompanying this there must be muscle exercise involving contraction so that the protoplasm may be stimulated to take up the nutrition. Muscles may grow into a hypertrophied condition as is found in connection with the muscles of a laborer or the limbs of gymnastic operators. This hypertrophy is also found associated with the walls of the left ventricle in the heart produced as it is supposed in connection with the increased contraction of the aortic orifice. Opposite to this we find the atrophy of muscles particularly in connection with paralysis. In this condition the muscle become soft and relaxed, the examination of the muscle indicating the presence of particles of fat and other substances. In the paralyzed muscle striation becomes indistinct the fatty particles being found closely associated with the nuclei indicating the degenerative process.

Electrical Phenomena.—(1) Currents of rest. By removing a muscle from the body and placing two non-polarizable electrodes in connection with a galvanometer on two points of the body surface it will be found that a current is passing by the deflection of the galvanometer. This is called the muscle current and is best seen when the muscle is made up of parallel fibres and when it is cut off from its tendon relations by right angle incisions to the muscle fibres. In this case we have a longitudinal section of a muscle with clean cut transverse sections at the ends. The longitudinal surface is divided into two equal parts by an ideal line called the equator. It is found in such a muscle that the greatest current is passed when one of the electrodes is put on the equator and the other at one of the transverse ends, the current passing from the middle or equator to the transverse end through the galvanometer, indicating that the end is negative to the equator. The current is the same whether the electrode is at one end or the other. If however the one electrode is moved from the end to a point nearer the equator the current is of the same direction as before but its intensity is lessened. By placing the two electrodes at points of unequal distance on either side of the equator a weak current passes from the one nearer the equator to the other, the current differing as they come nearer equi-distant so that if equi-distant there will be no current at all. By placing one electrode at the center of the cut end and the other at the margin a current will pass from the latter to the former. The most positive and the most negative points to each other are on the equator and the centers of the cut end and the degree of current will depend on the distance from these points. These muscle currents are found even after the circuit is closed so that they must depend on changes found in connection with the muscle arising probably from chemical changes. They are foundto disappear when the muscle loses its irritability so that they depend on the same conditions as irritability. Muscle currents are found in all muscles, more characteristic in cylindrical than in irregularly shaped muscles. According to DuBois-Raymond they are necessary characteristics of all muscles. According to him the muscles consist of regular molecules possessing electromotive forces, each molecule having like the muscle an equator that is positive and ends that are negative, so that when the whole number of these molecules is combined in the muscle we have a large bundle of electromotive particles. There would not seem to be any foundation for the theory that these originate in the deeper parts of the muscle, the currents being

purely superficial. In an uninjured muscle the currents are much feebler than when the muscle is divided up into cross sections.

From this it is evident that there is less of a muscle current at the natural muscle ending than in the case of the transverse ends so that if the natural end is injured in any way then the negativity increases. To such an extent is this the case that if the muscle is very carefully treated in its normal condition there will be no current at all indicating its iso-electric condition. In connection with the ventricle of the heart of the frog the superficial surface if not injured does not give any electric current, but by injuring the surface or cutting the cardiac muscle across there is developed at the point of transverse cutting a strong negativity. This negativity is found to be destroyed when the result of injury is absent so that it can only be produced by a new injury to the muscle. This has been explained in connection with cardiac muscles by the fact that the fibres are shorter and not like the ordinary skeletal muscle fibres so that in the case of cutting the cardiac muscle a number of these small fibres are injured producing the negativity which lasts only for a short time because of the shortness of the fibres, while in the longer skeletal fibres the negativity is transmitted along the fibres. When a muscle is cut the death of the fibre takes place at the point of injury, so that it is claimed these muscle currents do not exist in the living normal muscle but that they result from changes taking place in connection with the process of dying, the dying portions of the muscle being negative to the rest of the muscle. It is claimed therefore that these currents represent artificial currents.

In the case of the muscle the liberation of energy takes place in the form of heat, work and electricity while in the nerve the only manifestation of activity is found in connection with electrical change. The electrical energy represents a transformation of potential into actual energy the electricity arising in connection with chemical changes in the muscle and nerve so that stored up energy is liberated. In the case of the nerves we know of no chemical changes although there must be some to account for the electrical phenomena. While there are electrical phenomena in connection with muscle and nerve this does not mean that muscle and nerve activity are electrical the activity being simply manifested in this way. The same activity may be manifested in other organs and tissues in connection with electrical changes, for example, in plain cells, gland cells etc. In some of the fishes there are found special organs of electricity capable of discharging a large amount of electrical energy. In testing these current the galvanometer is used because of its great sensitiveness to electric currents when they are very feeble. Another instrument of great delicacy is the capillary electrometer consisting of a glass tube in capillary form the end of which is dipped into a glass vessel containing a ten percent solution of H_2SO_4. The upper end of the tube is connected by a rubber tube with a pressure bulb containing mercury so that by raising the pressure bulb the mercury is passed into the capillary against the capillary resistance. If the pressure is strong enough the mercury may be driven to the capillary extremity driving out all the air the mercury rising when the pressure is taken away pulling the H_2SO_4 after it. The mercury rests when the pressure and capillary resistance equilibrate each other. The end of the mercury column in contact with the H_2SO_4 is convex and any change in this convexity produces a movement of the mercury; this change in the mercury may be produced by a very slight current of electricity. The movements of mercury can

be calculated by means of a graduated scale in connection with the microscope and can be easily photographed so that very delicate changes can be registered.

In the case of a normal muscle or nerve when in a resting condition there is no electrical variation and hence they are said to be iso-electrical. By the injury to the tissue there is at once a change which may be detected by the galvanometer or electrometer. Tissue when dead gives no current; the tissue when living if resting gives no current: whereas the dying tissue is negative to the living normal tissue; this is equally true of the nerve as it is of the muscle. In the case of the nerve of a cat Horsley finds that the e. m. f. is .01 of a Daniel's cell, in the spinal nerves .025 and in the spinal cord .046. The non-medullated nerves give a larger current than the medullated because of the greater number of axis cylinders. In the case of a nerve the current of injury is of short duration because of the shortness of the extent of the nerve to the first node to which death takes place. A nerve can be stimulated by the current arising from its own injury so that we have a current in the case of mechanical injury strong enough to produce an irritation.

(2) Currents of action. In the case of a muscle when active as distinguished from resting muscle there is an electrical negativity. The same is true of the nerve tissue when active. Raymond found that by connecting the longitudinal and cut surface of the muscle with the galvanometer and tetanizing the muscle there was a deflection opposite to that found in connection with the current of rest. He proved that this was not due to the diminution of the resting current by producing a current from a battery to compensate for the resting current, the deflection still taking place in the opposite direction. This current of action in the opposite direction Raymond called the negative variation finding that it continued only so long as the muscle continued in the tetanized condition. When the stimulation is removed the deflection ceases and the ordinary current of rest is restored although not perfectly by keeping up the stimulation so as to increase the current of action several times the return to the original position of the current of rest is lessened. This indicates that a current of electricity is developed as soon as the muscle begins to contract so that as the currents of rest are diminished there is a negative variation of the currents of rest, this negative variation being found not only in the tetanic condition but also in a single contraction. This current of negative variation may be utilized as a shock in the stimulation of muscle. By taking two muscle nerve preparations and placing the nerve of one on the muscle of the other, as soon as the nerve of the latter is stimulated there will be found a twitching not only of the latter but also of the former muscle. By stimulating the nerve electrically with several rapidly succeeding induction shocks so that the one muscle becomes tetanized the other muscle will also pass into a tetanic condition. This is not caused by the passage of the current of electricity from the one nerve and muscle preparation to the nerve of the other for the tetanic condition of both muscles ceases by ligaturing the first nerve stimulated. The one muscle acts as a battery; when the connection with the other muscle is established by means of the nerve it serves as a stimulation to the second muscle. As each spasmodic action of the tetanic condition of the one muscle takes place a negative variation arises in connection with the muscle current, this negative variation current of the one muscle stimulating to spasmodic action the other muscle; and as the shocks are rapidly ap-

plied to the first nerve these produce rapid shocks in connection with the negative current so that the primary tetanus produced by the induction shocks leads to a secondary tetanus in the other muscle through the current of negative variation. This seems to indicate that a negative variation current consists of a series of negative variations and Raymond regards this as a proof of the discontinuity found in connection with the so called tetanic contraction, because the second muscle could only have been tetanized by a number of stimuli. Although there were a number of separate electric shocks in producing a current of negative variation in connection with the tetanus it did not produce fusion of the negative variation currents; consequently producing a secondary tetanus. By the use of the electrometer records have been obtained of these variations in electric currents found in connection with an injured muscle when tetanized representing the negative variations that tetanize the second muscle. Sanderson by the use of photography has pictured those changes pointing out that there are diminutional effects representing a more permanent variation that diminishes the result of a negative variation in connection with the injured tissue. This continuous alteration arises from the continued contraction found in connection with the contracture of tetanus. It is taken to represent the difference in contraction between the normal uninjured part of the muscle and the injured part,the latter part giving only an incomplete contraction while the contraction of the former is perfect. The diminutional result is found therefore only in connection with injured muscle. By stimulating the muscle with a single stimulus in connection with the nerve there is a double phase in the resulting variations, the part directly stimulated being first to manifest activity and therefore becoming electrically negative. this condition passing gradually to the rest of the muscle.

By placing one electrode close to the point of stimulation of a muscle and the other electrode at an indifferent point, by the use of the electrometer it will be found that at each stimulation a diphasic variation takes place. As soon as stimulation takes place the point at the first electrode becomes negative to the point at the second electrode in the muscle: after the wave of contraction reaches the point at the second electrode it will be negative so that it will be negative to the point of application. As in the normal condition the wave of contraction passes in two directions along the muscle from the point of stimulation there will be found two diphasic variations in connection with each stimulation. In connection with the heart in normal conditions we find these diphasic currents, during the first phase when the contraction originates at the base, the base is negative to the apex, and in the second phase the apex becomes negative to the base. When the cardiac muscle is cut or injured the negative variation stops at the point of injury so that only a single phase is observable. These diphasic variations have been fully investigated by Waller who has made records of the electrical variations in connection with the heart rhythm. So marked have been these diphasic variations in the electric condition that each heart beat produces a stimulation strong enough to produce from one to two contractions in connection with the muscle nerve preparation. If the heart is stopped in diastole by the stimulation of the pneumogastric a positive variation is found in connection with the muscle current. Gaskell has shown that in this case the inhibitory action of the nerve is accompanied by a positive variation electrically in the current of the heart; if the heart is stimulated by the sympathetic nerve, represen-

ting the acceleratory impulse, an electrical variation is also found. In both of these cases electrical variation can be produced in the heart even after the heart is stopped by the use of muscarin. This seems to indicate what is the nature of the action of the vagus and sympathetic nerves upon the heart. Waller has concluded that the excitation of the ventricle starts at the apex and is distributed towards the base. On account of the slanting position of the heart the cardiac variation may be found by connecting the two hands or the right hand and one of the feet with the electrometer. The first phase in the cardiac variation is of shorter duration than the second phase, Bernstein in connection with these diphasic changes claims that the period intervening between the two phases is in direct proportion to the distance found between the electrodes and that the variation is transmitted at the same rate as the wave of contraction. He found that the negative variation originated just at the moment of irritation so that there is no latent period. The negative variation therefore does not represent any latent condition preceding contraction but forms a part of the contraction itself, the negative condition lasting throughout the contraction period according to Sanderson. It has been usually considered that the negative wave of the muscle current precedes the contraction wave but as we have seen both waves have a velocity of about three meters per second. According to Lee the negativity in connection with the muscle of a frog lasted not only during the contraction period but even during the relaxation period. In connection with some recent cases Sanderson found that the negative variation lasted not only during the contraction period but continued after the removal of the stimulation, indicating that it represents a process associated with the muscle contraction and may continue even after the contraction ceases as an after affect. Not only is there a current in connection with the tetanus of muscle but there is also a muscle current during a single contraction. In this case the electrical variation is found preceding the period of latency in the muscular contraction, according to Waller the variation beginning from .04 to .1 of a second after stimulation the contraction taking place from .1 to .3 of a second after stimulation.

Some claim that there are natural muscle currents while others deny the existence of these natural currents but admit that during the contraction of a muscle there are developed currents of action arising in connection with the muscle substance as it enters upon the contraction, the contracted muscles becoming negative to the rest of the muscle substance remaining at rest. In this sense the negative variation represents the initial condition of a contracting muscle whether normally contracting or contracting in connection with the rigor mortis condition. In the normal muscle the negative wave would originate from the motor plate when the muscle is stimulated through the nerve, or from the point of stimulation when it is stimulated directly, the wave passing over the muscle to the ends of the muscle substance. In the case of the tetanization of a muscle, wave following wave of negativity will pass along the fibres, the first wave being more marked than the second; the result being as we have seen before that a succession of stimulations may pass from the muscle in connection with those currents of negative variation.

In the case of the nerve we find the same principle applicable as in the case of the muscles. By the stimulation of a normal nerve there is found a negative variation at the point of stimulation from which it passes in both directions along the nerve path, having the same rate as the neural

impulse. This electrical variation in the nerve is diphasic, the first phase being found associated with the part that is stimulated, and the second phase in the parts at a distance from the point of stimulation. By injuring a nerve the second phase is not found on comparing it with the normal nerve. By frequently stimulating a nerve there is aroused a number of currents corresponding with the number of stimuli. The negative variation in connection with a single stimulus is found to vary from .007 to .025 of a second. There is also a variation in the intensity of a current, the current however may be so strong as to furnish stimulation to another nerve. It is found that the nerve cells and the muscles in connection with the nerves are very sensitive to these neural stimulations so that a negative variation is found to follow a nerve impulse produced by the stimulation of the nerve in connection with the nerve cell. Raymond found a diminution of the current of rest in the case of poisoning by strychnine, the spinal cells stimulating the anterior roots very strongly, resulting in strong muscle contractions. Horsley made use of electrical stimulation in connection with the peripheral nerves, the spinal nerves and the motor tracts in the spinal cord finding that by stimulating the cortical cells in the motor region there was found in connection with the nerves a current of action of the same rate as the motor impulse sent out from the cortical cells. It is not known that the nerve impulse in connection with these currents of action varies in different kinds of nerves at least in the nature of the impulse; there is however a variation in the intensity depending upon the manner of stimulation. In all cases the impulse is associated with a current of action which represents a negative variation. By placing a nerve on one of the electrodes transversely and longitudinally on another electrode it is found that if electrical stimulation is applied there is a diminution of the nerve current. This diminution in the form of a negative variation is transmitted very rapidly as periodic interruptions along the nerve and passes through the muscle. Hering has found that in connection with the nerve there is a secondary tetanus similar to that found in connection with the muscle, the extent of the negative variation depending on the extent of the primary deflection. There is no negative variation observable if the nerve is uninjured. In the spinal cord the same negative variation is found as in the nerve. By conducting a current from the transverse and longitudinal portions of the medulla interrupted negative variations are found, possibly arising from the intermittent stimulation of the nerve centers. The negative current is transmitted along the nerve at the same rate as the nerve current, namely, about 27 meters per second. The transmission is assisted by a temperature ranging from 15 degrees to 25 degrees C. Bernstein has measured the velocity of the negative variation in connection with the nerve by the use of the differential rheotome. This negative variation is found to be entirely absent in the case of nerves that have become degenerated.

By taking a freshly removed eye-ball and placing it on a non-polarizable electrode in connection with a galvanometer and permitting the light to fall upon the eye there is found to be a retinal current from the cornea to the transverse section of the optic nerve fibre and it is found that this increases, the optic nerve at its cross section being negative to the cornea. By stimulating the secretory nerves in connection with glands it is found that there is not only produced stimulation resulting in secretion but also an effect upon the current of rest, called the current of secretion. This current of secretion is found to travel in the same direction as the current

of rest, although Hermann claims that in the frog it sometimes travels in the opposite direction.

As we have seen when a stimulus passes along a motor nerve into a muscle certain changes take place which are chemical in their nature. It is natural to suppose that these changes are connected in some way with electrical variations. The relation between these has not however been very clearly established. Animal electricity was discovered about 1786. In experimenting in connection with frogs Galvani found that when the frog's skin came in contact with a metallic surface as they were suspended from copper hooks there was produced an electrical current. He claimed that the spasmodic actions in the frog were due to animal electricity originating from the animal tissues. Electricity at this period was regarded as a fluid and Galvani concluded that electricity in the animal was a nervous fluid and associated in some way with life, with the bodily and mental functions. This view was criticised by Volta who experimented in connection with a frog in the attempt to discover whether electricity is natural or artificial. Volta first of all tried to prove that there was a mechanical stimulation but he found that if this stimulation did not take place in connection with the metals there was necessarily either no stimulation or stimulation took place only in connection with different fluids and tissues. Volta continued his experiments which resulted in his construction of the Voltaic pile by which he proved that electricity was developed by the contact of metals in connection with the fluids. To this discovery there has been added other facts, for example, electro-magnetism in which Oersted proved that by passing a continuous current along a wire parallel to a magnetic needle there results the deflection of the needle. This forms the basis of the invention of the galvanometer which has been so serviceable in connection with physiological experiments.

Various theories have been propounded in the attempt to explain the muscle currents. These theories are three in number. (1) The capillary theory formulated by Becquerel. It was claimed by him that there might be an electrical circuit in connection with the body without the use of the metal or metals. By taking two fluids of a different nature separated from one another by an organic membrane he found that electric currents could be developed. The membranous wall which is in contact with the liquid close to the acid gives us the negative pole while the wall of the opposite side represents the positive pole, the intervening spaces assisting in conduction. Becquerel claimed that in the body we find a large number of what he called "electro-capillary couples" originating constant currents of electricity. For example, in connection with the tissue capillaries the surface of the capillary walls towards the blood represents the negative pole while the surface in contact with the lymph represents the positive pole. The objection to this theory is that there is no proof of the reality of the generation of such currents of electricity in connection with the body tissues. (2) The physical or molecular theory. By taking a zinc cylinder with two pieces of copper attached to the sides and placing it in water it is found that there are developed a large number of electrical currents passing through the water as a conductor from zinc to copper. Part of the current may be lead away by attaching conductors to the zinc and copper and placing in the circuit a galvanometer, so that it can be shown that the zinc represents the positive and the copper the negative. Du Bois Raymond says that this represents

what is found associated with the muscle fibre which is found to consist of a large number of these electrical elements similar to the zinc and copper. In connection with these minute elements there is found according to him a positive equator with two negative zones so that when these elements are placed in a surrounding fluid medium physiological currents of electricity are developed. According to this theory each molecule represents an electromotive force or forces. We do not know histologically that there is any basis for this molecular theory but they represent according to Raymond the centers of chemical changes. Raymond in his first experiments supposed that he had found this electrical variation in connection with an intact muscle. He found however in his later experiments that by taking special care so as not to injure the muscle no electrical variation was fonnd in the uninjured muscle and even if such a current was found it was infinitesimal and in the opposite direction to the current of action. Raymond tried to explain this by claiming that in the intact muscle there is found at the tendinous end of the muscle certain molecules whose electrical poles are reversed so that in the muscle from the tendinous extremities there is a positive surface towards the transverse section which he called the parelectrotonic layer. According to this theory of Raymond a muscle or nerve consists of a number of electromotive molecules arranged one after another. All of these molecules have an equator and two negative polar surfaces in the direction of the transverse section. According to this theory the strong currents can be explained but no explanation seems possible in the case of the weak current, unless we suppose that a weakening takes place in the electromotive force at unequal distances from the equator. He explains the negative variation by taking it for granted that when a muscle or nerve is active there is a diminution in the electromotive force of all the molecules. If the contraction of the muscle is partial the part contracted becomes indifferent to conduction. In order to explain the electrotonic condition he assumes that there is a rotation of the bi-polar molecules. The action of the current upon the molecules is such that they rotate their negative surfaces toward the positive pole and their positive surfaces towards the negative pole so that the molecules between the poles are arranged in the form of a voltiac pile.

(3) The contact or difference theory. Hermann has strongly opposed the theories of Du Bois Raymond. He claims that in the uninjured muscle no current is found, claiming that the current is one of injury producing the death of a portion of the muscle fibre and thus giving rise to the difference in potential, hence called the difference or alteration theory. He claims that in support of his theory a great number of facts may be cited. It is almost impossible to prepare a muscle without injury because of the connection of the muscle by means of connective tissue with the skin. On account of this difficulty Raymond attempted to get the currents from the muscle without interfering with the cutaneous relations, but he found developed in connection with the frog strong currents from the outside internally. He tried to do away with those currents by saturating the skin with saline solution. Hermann objected that the saline solution had an effect upon the muscle acting on it chemically so that the current obtained was one of injury. In connection with fish muscle where no cutaneous current exists no current is obtained from the muscle when the fish is subjected to curari. Hermann claims that in the cardiac muscle when uninjured there is no current of rest although there

is a current of action. Putting these facts together Hermann claims that in the uninjured striped muscle there is no current. According to him such currents exist in the muscle fibre only when a portion of the fibre is dying while the other part continues to live so that when the whole muscle is dead there is no current. According to this the current orginates from the difference between the living part and the dead part of the muscle. by the use of the gastrocnemius muscle he has atttempted to measure the amount of the current resulting from an injury to the muscle; the current obtained in the normal muscle he calls current of action. This current passes from the longitudinal to the transverse surface of the muscle and he claims that this current of action precedes the contraction of the muscle. This corresponds according to Hermann with the negative variation, but he does not admit that any negative variation can exist in the case of the uninjured muscle. By the use of the rheotome Bernstein found by stimulating the muscle that it did not give a current of rest, a double deflection of the needle representing a negative and a positive variation. He found that this variation was transmitted through the muscle at the same velocity as the wave of contraction. From this he concludes that the negative variation or current of action is connected with the transmission of the wave of contraction so that while the wave passes each irritated muscle point comes to be negative to a point which continues at rest. This means that when the wave has reached a certain point it comes to be negative to a point that is still beyond the wave. When a muscle is fully tetanized there is no current of action. If the Raymond theory is correct then we would expect that in the living human muscles there would exist currents and that a negative variation would be found in connection with voluntary contraction. This however is not found. By saturating the hand in a saline solution and then contracting the muscles of one arm there is a deflection of the needle and by contracting the other arm the deflection of the needle is in the opposite direction. Raymond considers this a negative variation but Hermann says there is no muscle current but that it is a skin current and that it is due to the saline solution with which the skin is saturated, in other words it implies a secretion current. According to Hermann, therefore, all the muscle currents are due to two kinds of physiological change; (a) the part of the muscle dying being negative to the part living; (b) irritation of a part of a muscle causes it to be negative to the unirritated part.

According to Hermann when protoplasm begins to die, the dying portion becomes negative to the uninjured part; when it is irritated it becomes negative to the unirritated part; when it is cooled and warmed it becomes negative and positive to the normal part; and the surface of the muscle is very strongly polarizable, polarization decreasing with the death of the muscles. Hence purely passive muscle is without any electrical currents, the currents arising from an injury or irritation of some kind. Hence when an injury takes place in a muscle or nerve there is a part of the substance that is dying and this part is negative to the intact part so that there is a demarcation current. When the part is completely dead it loses its negativity, this taking place in the nerves as far as the first node of Ranvier. This seems to indicate that the existence of currents in ordinary muscle and nerve cannot be sustained. During the activity of muscle and nerve as we have seen, there is an action current. In the muscle-nerve preparation including the gastrocnemius muscle with the sciatic

nerve of the frog, by the sciatic being dissected out from the spinal cord to the knee, by making a transverse section of the muscle and allowing the nerve to fall on the transverse section the limb will contract on the passage of a current from the transverse to the longitudinal surfaces. In this case we have contraction without any metallic substances.

When a constant current is made to pass through a nerve the nerve is said to be in an electrotonic condition. There is in this electrotonic condition a modification of the neural properties. These modifications consist of changes in electromotivity, in irritability and in conductivity. (1) Electromotivity. By arranging a nerve so that the transverse section rests on one electrode and the longitudinal on the other there will be found a strong current. By passing a constant current through the nerve end projecting beyond the nerve point on the electrode and by sending a current in the same direction as that of the nerve there will be an increase of the nerve current representing what is called the positive aspect of electrotone. This increase in current becomes greater as the length of the nerve is increased. By sending the current in the opposite direction to that of the nerve the electromotive force of the nerve is diminished and this is called the negative aspect of electrotone. Hence a constant current produces a change in the electromotive force on the part of the nerve through which the current passes and also in the part beyond the electrodes. This condition is called the electrotonic condition. In the case of a secondary contraction or tetanus of a nerve it depends upon this electrotone; for example, in the case of the sciatic nerve it divides into a tibial and a peroneal branch; if the sciatic is divided above their point of junction and the peroneal branch is then cut and stimulated by a constant current the muscle in connection with the tibial branch of the nerve will contract. A similar electrotonic condition is produced in the muscle by the constant current so that if the current is in the same direction as the muscle current it is increased and if in the opposite direction it is decreased. By passing a constant current through a nerve the nerve stimulation produces a variation in the current. This arises not from the nerve resistance but from changes in connection with the commotion as it passes along the nerve. By passing a Voltai current through a nerve and the intrapolar region in connection with a galvanometer as soon as the current isopened there will be found a deflection either in the same direction or in the opposite direction or the deflection may take place first in one direction and then in the other. These electromotive results in the case of polarized nerves are capable of explanation on the basis of the fact that when the polarizing currentis flowing the conductivity of the nerve in connection with the impulse is lessened at the negative pole and that when the current is opened the reverse of this is the case. (2) Electrotonic irritability. As we have seen when a nerve is traversed by a constant current it becomes electrotonic involving a variation in irritability as well as in electromotivity. This change passes over the entire nerve both intrapolar and extra-polar. The irritability is lessened at the positive pole and increased at the negative pole. Between the poles there is a point that is indifferent where the irritability is unaltered. In the case of a feeble current this neutral point is nearer the positive pole and in the case of a strong current nearer the negative pole; in the former case a larger part of the intrapolar region being irritable than in the latter case. Where the currents are very strong conductivity at the positive pole is very much lessened and in some cases conductivity may be impossible.

The extrapolar area becomes larger as the current is increased, the electrotonic effect being increased as the length of the nerve is increased.

Stimulation of a nerve takes place at the time the electrotone appears and disappears, in other words at the opening and closing of the current. (1) At the closing of the current the stimulation takes place at the negative pole; (2) at the opening of the current it takes place at the positive pole, so that (3) the stimulation of the closing is stronger than that at the opening of the current. These principles apply in the case of all nerves. In the case of a constant current the opening and closing contraction varies with the direction of the current and also with the strength of the current, the feeble current producing only the closing contraction, the moderate current both an opening and closing contraction and the strong current only a closing contraction. In the case of a nerve when dying there is a modification of the law of contraction, when the irritability is increased feeble currents produce only the closing contraction; when the irritability begins to lessen feeble currents produce both opening and closing contractions; and when the irritability is greatly lessened there is only the one contraction, either opening or closing. The same laws apply to the sensory nerves as to the motor except that the organs of the reception lie in the central system. In the alteration of muscle and nerve under electrical stimulation when the alteration becomes qualitative and quantitative then there is what is called the reaction of degeneration. Muscle irritability is decreased in connection with the induced current, while it is increased in connection with the constant current; after eight or nine weeks there is a slight increase followed by a still further decrease. In the case of the nerves there is both a decrease to the induced and to the constant current. There may be a degenerative reaction before paralysis takes place, as in the case of lead poisoning. This depends upon the condition of the nerves either the fibres or the cells. When this reaction is fully established the stimulation of the nerve with the constant or induced current does not produce contraction of the muscle; stimulation of the muscle directly with the induced current does not produce contraction while the constant current stimulates the muscle even more readily that in normal muscle conditions, although the contraction becomes tonic and is longer than normal indicating a tendency to tetanus. When the paralysis originates cerebrally the irritability under electrical stimulation is not affected. The same is true of primary paralytic conditions of the spinal cord while in cases of paralysis originating from injury and in some cases where there is paralysis produced from other causes as in lead paralysis and rheumatic facial paralysis there is the degenerative reaction.

The laws of electro-physiology in connection with muscle and nerve may be stated as follows: (1) All the different parts on the surface of a muscle when not injured and in a resting condition have the same electrical potential. (2) If a part of a muscle or nerve is injured that part represents a higher potential than a point that is uninjured and hence represents the flow of an electric current. (3) Any part that is unirritated in the muscle or nerve surface represents a higher potential that an irritated point so that here there is also a current of electricity. If a current is passed in connection with the unpolarizable electrodes through a muscle and nerve, there will be found a negative polarization current in the opposite direction, the polarization being distributed all over the intrapolar re-

gion representing an internal polarization arising from the individual elements in the tissue. As this polarizing current is flowing there are found appreciable changes especially in the extrapolar region and particularly in the case of the nerve. These currents are called the electrotone currents and depend on the diffusion of the polarizing current along the nerve path beyond the electrodes.

Electricity is made use of therapeutically (1) in diagnosis. Here the induced current may be used as a test of muscle and nerve irritability in connection with the moistened skin. In this way the current passes over the skin without affecting it passing internally into the muscle or nerve. If the sensibility of the skin is to be tested then the current is applied to the skin dry and powdered, the current being used up to the point of pain in testing the difference in sensibility. Electricity forms a convenient method of testing in paralysis for the cause of the condition. The lesion may be either central or peripheral, that is, a lesion which cuts off the muscles from the higher centers or from the lower centers. In the former case the lesion would exist in the brain or in the cord above the point of origin of the spinal nerves; in the latter case the lesion would be in the centers that are at the point of leaving the cord or in the peripheral nerves. In the former case the muscles and nerves are still connected with the spinal centers so that by the use of electricity in the case of a central lesion the muscles and nerves would not have lost their irritability. In the case of the peripheral lesion the muscles and nerves are separated from the cord centers so that the trophic influences are shut off, the nerves degenerating and the muscles being similarly affected. In this case the irritability of the muscles and nerves is lessened and is gradually lost. It is found in some cases of peripheral lesions that when no response is gained to the induced current there is still a response to the direct current subject to interruption. This is explained on the basis of the fact that the muscle responds more freely to the direct current when interrupted because the currents are of longer duration. As the degeneration advances, however, even the direct current will cease to gain a response. This reaction of degeneration is found in rheumatic facial paralysis, neuritis, lead palsy and in lesions of the cells of the anterior horns of the gray matter of the spinal cord as well as in paralysis due to the injury of the nerve trunks. In cases of the supposed presence of foreign substances like bullets in the body, the constant current is often used in connection with a probe that is passed into the wound, connection being established with a galvanometer so that when the probe comes into contact with the metallic substance the deflection will indicate its presence. The induced current is also used to find out whether the muscles are dead as in two or three hours after the death of the muscles there is no response to stimulation. (2) Electricity is made use of as a therapeutic agent, for example, in the case of neuralgia with the object of soothing the pain. The feeble current is made use of so as to excite anelectrotonus in connection with the nerve and thus lessen the excitability. In rheumatic neuralgia the catalytic effects are produced with the object of scattering the inflammatory products. In hyperaesthesia the induced currents are used to produce over stimulation and therefore to produce a numbness of the parts. The use of the weak current will produce an acceleration of the blood flow, an increase of the cardiac action and a constriction of the blood vessels. In cases of headache, feeble currents may be used, one electrode being placed on the forehead and another at the upper part of

the neck. In case of spasms the constant current is the best form of electricity for use. An electrotonic condition is produced so that the excessive excitability is lessened. In order to produce this the positive pole is placed on the part with increased irritability, the weak current of uniform intensity being most effective. In wry neck direct application is made to the affected part. By the use of the constant current there is an increase of control over the muscles and the effect is to remove any irritating substance that may be found. The induced current is made use of in spasmodic affections such as tremors to invigorate the enfeebled muscles, the muscles when in a condition of contracture being more easily extended under the influences of the induced current.

The most common use of electricity is in connection with paralysis. The induced current may be applied either to the muscle or to the motor nerves before they reach the muscle. The purpose is to produce movements of the muscle and so to prevent the inert condition which is sure to result in degeneration. There is also in connection with the use of the induced current a stimulation of the blood flow increasing the muscular metabolism. The constant current may also be used in connection with its opening and closing as a stimulus. In connection with a constant current there is a recuperative effect on fatigued muscles by the passage of a previous current through them. If the paralysis is in the motor nerves the electricity is brought to bear upon the nerves, the current being feeble so as to prevent tetanus in the muscle which would produce exhaustion. A dying nerve in connection with a muscle does not respond freely to quickly interrupted currents. In the case of facial paralysis the constant interrupted current is best because there is a longer duration in the current between the interruptions. Hence in using the current therapeutically two things must be considered, namely, the strength of the current and the duration of the current. In partial asphyxiation due to chloroform or in the lessened respiratory action associated with opium poisoning the induced current may be applied to the phrenic nerves, one electrode being placed over the scalenus anticus and the other in the sixth or seventh intercostal region.

(3) In electro-surgery electricity has been applied. In connection with electrolysis the constant electric current disintergates the tissues. Thus it is applied in the decomposing of tumors, the negative pole having a greater caustic effect than the positive. The negative pole is attached by means of needles that are put into the tumor while the positive pole is placed at an indifferent part of the body. In cases of aneurism the galvano-puncture method is used to produce coagulation in the aneurismal sac. In the cautery the electric currents are also used, the electrodes being made of platinum on account of their readiness to become red hot. In the use of this method of cauterizing the tumor may be rapidly cut through and hemorrhages prevented because of the action of the current in producing coagulation. If a current of electricity is passed through defibrinated blood the proteid matter coagulates at the positive pole and the gas is collected at the negative pole. In amputation in connection with the tongue the cauterizing loop is very commonly used. The galvano-cautery knife is also used commonly, particularly in small passages like the throat and the nasal cavity, as in hypertrophied conditions of the mucous lining, in enlarged tonsils and in haemorrhoidal conditions of the rectum. These are but indications of the importance attached to electricity in connection with its physiological, therapeutic and surgical ap-

plication.

ELECTRICAL FISHES.—Some very interesting facts in connection with animal electricity are found in the fishes. This is made use of as a means of illustrating the action of muscles and nerves in connection with electricity. The work of Raymond, Burdon-Sanderson and Sachs is especially interesting along this line. There are found to be about fifty different kinds of these electrical fishes; very few of these however have been investigated. The subject is the more wonderful when it is found that there is a regular electrical apparatus and that it is used as a means of defense in connection with the fish life. The best known specimens of these are the torpedo found in the Mediteranean; the gymnotus an eel like fish found in the lagoon region of South America; the malapterurus or the thundering fish of the Arabs found in the Nile River; the mormyrus a form of pike found in the Nile; the Rhinobatus found in Brazilian waters and the trichiurus found in the Indian Ocean; and the raia batis or skate found along the American coast. These electrical fishes have been well known from ancient times, Aristotle describing the effect of torpedo shocks upon fishermen and the malapterurus being historically known among the Egyptians in very early times. In the torpedo there are two electrical organs which lie immediately beneath the skin, flat-shaped bodies on either side of the head. The electrical organ is made up of about 800 prisms of a hexagonal nature lying in a vertical direction between the dorsal and abdominal tegument separated from each other by a series of membranes. In these organs there are a large number of electrical plates each plate being furnished with a nerve fibre, the plates being separated by a gelatinous substance. In each organ there are estimated to be about 500,000 of these plates. In this way we have a strong electric battery divided into a series of compartments each compartment being freely supplied with nervous connection. Each of the nerve fibres as it enters the prism is divided up into a large number of fibrils each plate receiving a fibril. The nerve connections are established in connection with the trigeminal and the vagus nerves. In the prism the nerve ramification is found in a very vascular substance, each prism representing an electric pile, the piles being vertical and the plates being horizontal. The nerves originate from the electric lobe that lies between the corpora quadrigemina and the medulla. These electric fibres pass through the gills entering into the organ in connection with five branches, four from the vagus and one from the trigeminal. After entering they divide, the branches running between the prisms and entering at the middle of the prism. The chief nerve enters the center of the prism, the individual fibrils passing in a straight line along the column and entering into the plates. After reaching the plate the fibril divides into two, all of the plates having corresponding fibrils.

According to Ranvier between each pair of plates there are four layers, (1) a layer of nervous tissue consisting of a superficial part in which is found the nerve fibrils and a deeper layer which manifests peculiar cilia shaped hairs which lie alongside each other; (2) an intermediate layer consisting of a superficial part of delicate granular matter and deeper part of more coarse granular matter in which is found the nuclei; (3) A third layer of delicate clear tissue which Ranvier calls the dorsal lamella; and (4) a connective tissue layer which forms the septa. In this organ we find a close relation to the muscle tissue. Fritsch has found that the torpedo in its history passes through three stages, the first called squali-

form in which there is a resemblance to the embryo of the shark; second the raiform stage in which the characteristics of the skate are manifest, and the third stage in which the true torpedo character is developed in connection with the formation of the electric organ. In its embryonic condition this electric organ is very like embryo muscle manifesting the distinct muscle striation with large numbers of nuclei. In later development the striation disappears the nuclei are enlarged and increased in number, this process going on until the organ becomes particularly differentiated. In the torpedo this electric organ is substituted for the external muscles of the gills. In the ordinary shark these muscles represent strong muscles in connection with the movements of the lower jaw. In the torpedo these muscles are not found, the electric organ being substituted for them.

In the gymnotus we find four different electric organs, a pair on each side extending from the fins in the pectoral region towards the tail. These electric organs are much larger in size than those found in the torpedo. The visceral organs in the gymnotus are found to occupy only a small portion of the front part of the body. In each electric organ we find a series of plates following the longitudinal axis of the body. There is a division by means of delicate vertical lamina each lamina consisting of two separate layers between which is found a liquid. In the posterior layer we find the ramification of the nerves while in the anterior layer there is a very vascular tissue. Between the layers there is found a fluid quite different from that which is found between the posterior and the anterior diaphragm of the next lamina. The characteristic of the fluid is its albuminous nature. According to Fritsch there are found in the organ a series of septa consisting of connective tissue the electric plates lying between these partitions. In connection with these partitions there is found an albuminoid substance. On the anterior surface of the plate there are found a large number of projections with rounded extremities in connection with which are found granule cells. Lying between these projections and the anterior septum of connective tissue is found a mucous fluid in connection with which there are found cells. The middle portion of the plate is found to be very clear although when removed from the body there is found to be an equatorial line dividing the plate in two. On the posterior surface of the plate there are also found projections differing in size, some being rounded and others conical as well as longer in size, the latter extending to the posterior septum of the connective tissue. According to Fritsch these are the portions of the organ in which the terminals of the electric nerves are found. The nerve fibrils are found to pass over the anterior portions of the septa and before they enter the projections they lose their medulation entering the plate simply as an axis cylinder. The small fibrils enter into the posterior surface of the plate. These plates originate out of muscle, each plate corresponding with a number of original muscle fibres bound together. In some places the plates are found to correspond with the individual groups of fibres there being a longitudinal dividing line separating the groups. In other cases the dividing line is found to be transverse. In the gymnotus the cells with which the electric organ is connected are found to be throughout the spinal cord. The electric organ is not large being flat shaped in the anterior portion, flattened at the posterior portion and rounded at the central part. In connection with the spinal cord there are found to be connections in the form of cells, these cells being surrounded by the central canal of the spinal cord. Arising

from the processes of these cells are found the axis cylinders which pass out through the anterior group from the spinal cord to the electric organ. These electric groups go side by side with the motor root to the intervertebral foramen. The other processes of these electric cells in the spinal cord enter the neuroglia their termination being unknown. These electric cells are of a circular shape being found to consist of very granular matter with characteristic polarity in connection with tne axis cylinder. In connection with the spinal cord the normal multipolar cells are diminished as these electric cells are increased, the motor cells being found in the anterior horns of the spinal cord. These motor cells are polygonal in shape, the poles not being so distinct as those found in connection with electric cells. Fritsch thinks that the development of cells is from motor to electric so that the development can be noticed as the cell becomes more circular, as the granular matter increases and the polarity becomes more determinate. He has traced out some of these cells in the process of transition in connection with the anterior horns, particularly in the cervical part of the spinal cord. Towards the lower end of the cord there are found to be fewer of the electrical cells the distinction between them and the motor cells becoming less marked.

In the case of the malapterurus the electric organ consists of a delicate layer lying under the skin surrounding the whole body except the head and the portions covered by the fins. It is separated from the muscles that lie beneath by a layer of fatty tissue. In this electric layer there are found a number of spaces which are filled with liquid, the electric substance being found on the walls of these spaces. The electric substance is found to be very granular with double nuclei. In connnection with the marginal surfaces there are found to be striated tubules. In connection with the nucleus the protoplasm is more transparent, the broader tubular portion being separated from the narrower and more indistinct portion. Surrounding each of these spaces there is found to be a membranous substance. Fritsch considers the electric substance to be giant cells of the epithelial form, the internal surface being covered with a mucous liquid. In connection with the cutaneous surface there are found peculiar shaped cells with two nuclei which Fritsch considers to be intermediate forms in transition towards the electric cell form. The electric substance is not found to the same extent in all parts of this electrical layer particularly in the posterior part of the body. These peculiar shaped cells represent the electric unit according to Fritsch there being as many as 2,000,000 in a single malapterurus. Fritsch has shown that when the nerve reaches the electric organ it enters on one side of this space as a non-medullated fibre and that it gradually insinuates itself into the electric substance. The most delicate of the fibrils that are found between the cells represent very delicate axis cylinders medullated with the characteristic nodal points. As the nerve becomes larger there is found to be an axis cylinder and medullary substance, the nerve itself being encompassed by connective tissue in connection with which the capillary system is found and even delicate nerve fibrils. These electric nerves can be followed to the spinal cord, are found to be developed from a single electric nerve whose axis cylinder passes into the cord and terminates in one of the giant cells. This large cell is found to have a number of processes which are united together in the formation of a plate in connection with which there are found both nerves and blood vessels. The axis cylinder as it originates from one of the processes of this plate

is small in size and as it passes out it furnishes minute fibrils to the electric organ. In connection with the malapterurus there is found to be a perfect lateral nervous connection, the electric nerve being found in connection with the trigeminal nerve. In connection with the electric organ it was found by Raymond to be neutral in reaction becoming acid after death. Hence he claims that it is analogous to the nerve tissue, that is found associated with the central nervous system and hence characteristic nerve tissue. Landois differs from Raymond in regarding the electric organ as a modified muscle, the terminal plates corresponding with the motor plates in muscle, these terminal plates being highly developed, so that while the organ is active there is really only an electrical variation without any chemical change. It is claimed that in development the organs are formed just as the muscles are formed and it is claimed that they contain, if not myosin, a substance very similar to myosin which is found to coagulate after death. In addition to this it is said that they become fatigued and when subjected to stimulation they have a latent period. Marey claims that in the discharge of electricity they pass into a process that is analogous to tetanus. Fritsch claims that the electrical organ is developed out of cutaneous glands which pass through a process of modification.

In the Raia batis or skate we find a fusiform electrical organ just beneath the skin on either side of the tail. This organ consists of a large number of longitudinal discs, these discs being found side by side in rows with two separate discs the one looking forward and the other looking backward. Over the anterior surface there is found to be a layer of nervous substance in connection with which a number of nerve fibres terminate just as the nerve terminates in a muscle plate. On either side of the spinal cord towards the tail of the fish there is found underneath the skin an elongated body which consists of these longitudinal discs. In connection with the discs there are found tubes which are formed by dividing layers of connective tissue. The anterior surface is flattened while the posterior surface is concave and in it there are found a number of alveolar depressions. There is thus a similarity between the electric organ of the skate and the gymnote, the nerves arising from the anterior roots of the spinal nerves, these nerves passing along with the anterior roots and going to this electric organ. It is not supposed that there are any special ganglion cells in the spinal cord that may be called electrical. The most characteristic of the electric fishes is the torpedo, although the discharge of electricity in connection with the malapterurus is very much stronger. It is claimed however by Raymond that the strength of the torpedo shock is lessened very materially by the salt water medium in which it is placed and hence it is said that if the malapterurus is placed in the same salt water medium it loses a large amount of its electric energy. In connection with the torpedo the electric organ is to a certain extent subject to the control of the will because when stimulated there may or may not be an electric discharge. By removing the brain and then irritating the organ there is a discharge of electricity on the same side as the irritation. From this it is claimed that the electric lobe represents the electric centers and that these may be stimulated reflexly by stimulating the cutaneous surfaces and also by irrritating the nerve that passes to the organ. This reflex discharge is found to consist of a succession of shocks compared by Marey to a tetanic condition of the muscle. As the organ is excited the discharge takes place after the lapse of a latent period, Gotch finding

that there is a distinct period intervening between the stimulation and the response in the discharge of electricity. The response takes place after the period of latency very suddenly, a high electromotive power being developed after which the discharge suddenly stops. By heating the organ to a temperature of 20 or 25 degrees C. there is a stimulation of the organ to electric discharge. The administration of curari does not seem to affect at all the stimulation or the response to the stimulation, while strychnine seems to produce a stimulation which causes the organ to discharge electricity. Pacini states that the distribution of nerves takes place to that portion of the electric plate which is found to be negative in connection with the discharge so that in the torpedo as the nerves are found in the under portion of the plate the electric discharge takes place from the ventral surface posteriorly; while in the gymnote the negativity is found in the posterior part of the plate and hence the shocks pass from the posterior to the anterior part of the body. Gotch says that the electric discharge may take place in three different ways, (1) in connection with the stimulation of the nerves either directly or reflexly; (2) as a result of a strong current passing through the organ which produces a very strong discharge; and (3) as the result of a thermal or mechanical stimulation in connection with the organ. In connection with the gymnote an electric discharge may take place by mechanically stimulating the cutaneous surface. The resulting discharge is slight and the full discharge can be found only when the current passes through the entire circuit of the body. Sachs found that by placing one foot on the head and another on the tail a series of shocks were received which caused considerable pain and at some times were sufficiently strong to throw him down. The gymnote has the power of killing fish, frogs, etc. in connection with the discharge of electricity. The passage of the current in the fish is from the tail to the head so that any part of the cutaneous surface is positive to the posterior parts and negative to the anterior parts. The gymnote does not seem to have the power of controlling the direction of the current although it has the power of defining the amount of the organ which may be thrown into activity so that it can limit the amount of the electrical discharge. In the case of the malapterurus, if it is touched a shock will be received. Raymond says that the discharge of electricity may be either voluntary or reflex. If a frog is placed in contact with its skin tetanus is produced in the frog. Compared with the size of the fish the electric shock is very strong. By seizing the fish with the hands particularly if the hands and the cutaneous surfaces of the fish are well moistened a strong shock passes into the hands and arms. Raymond says that the shock is not so great as that of a Leyden jar. Gotch says that a malapterurus can give to the fingers a severe shock by touching the head and tail, comparable to the shock produced in connection with three Daniel cells. He says that a shock can also be obtained if the fingers are placed in the water surrounding the fish while it is discharging electricity. The electric discharge is not sufficiently strong for the electrolysis of water although it is sufficiently strong to decompose iodide of potassium. A point of the organ close to the tail is found to be positive to any point close to the head. The electric discharge passes through the entire body of the fish and the discharge when accumulated seems to strike the central nervous system vertically to its axis. By irritating the electric nerve there are found to be emitted a number of rapid shocks. Gotch in experimenting on the malapterurus found that the discharge when stimulated elec-

trically in connection with the skin does not take place reflexly but results from a direct stimulation of the electrical organ. In connection with the skate the electric discharge takes place towards the tail so that the ends of the nerves are positive to the nerve trunks. If the surface of the body is stimulated mechanically there is a rapid series of electrical discharges. The anterior portion of the organ is negative to the posterior indicating that there is a current passing along the organ in the same direction as the discharge of the electric current. Raymond has tried to discover in what way the current is distributed in the torpedo claiming that the electric shock passes into the body of the fish and becomes most dense in connection with the brain and the spinal cord. He found that the currents flowed from the margins of the organ to the mesial line and in the visceral region from the median line to the margin going through the brain and spinal cord indicating that the current took the shortest path between the most active portion of the two organs. He has also shown that the curves which mark the direction of the currents as they pass out from the dorsal region in connection with the water and back again to the ventral region are directed outwards; and that on account of the larger inclination that is found in connection with the median line by causing the current to become slanting the dorsal region of the fish becomes protected while the ventral region does not need protection. The organ current represents a current of rest which is found in all electric fishes and which passes in the same direction as the electric discharge. Raymond claims that an importont function is discharged in connection with conductivity the insulating septa having an important function to discharge in connection with this conductivity. The current passes out from the upper end of a single column through the conducting medium to the lower end so that the current curves will be arranged in symmetrical form around the axis of the column. In this way the current curves will be found to be arranged in definite order in connection with the axis of the column. Gotch found that strong currents of short duration produce an irritable response in connection with the electric organ and that the strong current arising from this response is found to be a homodromous current. Gotch discovered that the electric organ may be stimulated secondarily by its own electric discharge so that he found by a single stimulation there resulted a series of responses at intervals of about .01 of a second, each successive shock being weaker than the one preceding. These currents of electricity which are found associated with the electric fishes seem to indicate a close relation between muscle and nerve in connection with the electric stimulation. In the torpedo the nerve terminal seems to be analogous to the motor plate in muscle and in the malapterurus to the glandular terminal of the nerve. The nerve commotion which is found to be associated with the molecular change in connection with the nerve produces a change in the end organ and from the end organ it is transmitted to the surrounding substance. Associated with these changes is a change in potential, one part becoming negative, the negative variation passing through the organ resulting in changes in connection with the organ. In connection with muscle this change is manifested in contraction, in connection with a gland it is manifested in a metabolic change and in connection with an electric organ in the discharge of electricity. In this way it is found that the molecular processes taking place in all of these changes are similar.

SECTION VIII. The Unstriped Muscle.

This muscle as far as it is at present understood in its physical, chemical and other properties resembles the striped muscle, but differences may arise on a full investigation of this form of muscle. When stimulated either directly by mechanical or thermal stimuli involuntary muscle contracts, but there are certain variations in the contractions as compared with the voluntary muscle. The contraction is preceded by a long latent period; the period of latent stimulation being very much longer than in the case of the striated muscle. The contraction takes place slowly and lasts some time and the period of relaxation is also prolonged. The general character of the contraction may be best seen in the movement of the intestines in the case of a recently killed warm blooded animal. In the œsphagus, intestines etc, the muscular fibres are arranged in an outer longitudinal and an inner circular set. When stimulated at one point the fibres at that point contract and the wave of contraction slowly passes along the tube affecting both longitudinal and circular fibres. This constitutes a peristaltic action or wave. Marey has shown that the contraction of nonstriated muscles is not made up of a series of smaller contractions as in the striated muscles, because most of the former are under the control of the will, while the latter as a rule are not subject to any influences from the will. There are however many exceptions to this general statement; thus the heart which acts involuntarily is composed of a variety of striped muscle and many of the striped muscles act under the influence of voluntary stimulation. Many of the striped muscles act in health and disease without any prompting of the will or any stimulation from the will. Probably the reason for the employment of one kind rather than the other for any particular purpose will be found in the fact that the action of the one is prompt and rapid while that of the other is slow and prolonged. According to Engelmann there may be radiation of impulses in the unstriped muscle. In connection with the unstriped muscle of the organs in which it is found we usually find rhythmical movements. There must be considerable strength associated with this kind of muscle because in the bladder and uterus we find a great force exerted in connection with micturition and parturition. The unstriated muscle is found usually as layers in connection with the coatings of the organs of which they form a part. The contraction takes place slowly and is continued as a slow and sluggish wave movement around the muscle. These muscles are like the cardiac muscles in this respect but they cannot be tetanized. The contraction that represents the slowest movement seems to be in connection with the cells of the vessel walls, a condition of tonic partial contraction being preserved which periodically undergoes a rhythmic variation. In the uterine walls the strongest form of the unstriated muscle is found, the contraction being very similar to the contraction of blood vessels the contraction taking place, however, more quickly, the relaxation representing also longer periods. In the intestines the unstriped muscle represents the most rapid contractile motion.

The special location of the smooth muscle is in the composition of complex organs like the intestines. It is for this reason that less is known of the unstriped muscle. It is found to contain albumin, globulin in some of its forms and some of the substances that are associated with myosin because after the death of the muscle these substances be-

come myosin in connection with the condition of rigidity in which extensibility is lost and acidity is developed. There is also found in connection with this muscle glycogen and kreatin indicating that the metabolism of the unstriped muscle is essentially similar to that of the striped muscle. In their physical properties they are also the same, being irritable and contractile under stimulation. There is a variation found in the length of the fibres, the intestinal fibres being longer and stronger than those of the blood vessels. Different conditions of the fibres may be found in the same muscle so that there may be a combination of different physical characteristics. The contraction of the smooth muscle has been more definitely investigated in connection with the intestines than any other form of the unstriped muscle. The coating of the intestines is found to consist of an external layer consisting of fibres and groups of fibres arranged longitudinally and an internal layer much thicker arranged circularly. The same arrangement of fibres is found in connection with the ureter. By the application of stimulation to the intestines in its living condition there is found to originate at the point of stimulation a circular contraction, the intestine manifesting the circular contraction as if it were partially ligatured, the result being that constriction takes place the blood being forced out so that the muscle assumes a pale appearance. The separate fibres in the circular layer have been shortened the result of which is the constriction of the lumen of the intestine. Similarly there is a contraction of the longitudinal fibres in the outer layer, the contraction taking place longitudinally, but on account of the comparative thinness of this layer the circular contraction prevails. There seems to be a physiological contention in the contraction between the circular and longitudinal layers, the result being that the former predominates because of its greater strength. In this contraction there is a preceding period of latency followed by a slow contraction which lasts for several seconds, the relaxation following slowly. In connection with the circular fibres there has thus been originated a contraction wave this wave passing from one fibre to another with slowness which is characteristic of this kind of muscle. The wave contraction is claimed to pass with a velocity of about 25 millimeters per second along the ureter the wave passing along the circular layer in both directions. At the same time the fibres in the longitudinal layer are contracted a contraction wave passing along longitudinally also in both directions. This wave of contraction differs from that found in connection with the striped muscle. In the striped muscle the wave of contraction is single passing along the fibre originating from the end plate of the muscle or on artificial stimulation from the point of stimulation. There is no radiation of impulse from one fibre to another. In the unstriped muscle the wave of contraction is not simple but complicated, resulting from the wave of contraction found in the several fibres and being transmitted from one fibre to another, both in the direction of the fibres and also at right angles to the fibre axis. In other words the changes that produce the contraction not only pass across the tissue substance which unites the fibres together but also from one group of fibres to another passing over the connective tissue possibly by means of nervous stimulation. In the case of the wave of contraction transmitted along a single unstriped fibre there is a difference in the latent period and the period of contraction as compared with the striped muscle, both of the periods being longer. Hence it is concluded that the entire length of the fibre in the unstriped muscle takes part in the contraction wave at one and

the same time. This double contraction of the circular and longitudinal layers forms the basis of peristaltic action as we find it in connection with the intestinal organs. These contractions may be originated by stimulating the nerves supplying the muscle, these nerves being mainly in connection with the sympathetic system, although they have established relations with the cerebro-spinal system. In the case of the striped muscle contraction takes place normally only through nervous stimulation although it is claimed by some that there are spontaneously generated certain contractions in connection with the skeletal muscles; but these are entirely abnormal and may possibly be originated solely by nervous stimulation. In the case of the smooth muscles of the intestinal organs and of the blood vessels there are contractions undoubtedly which do not depend for their stimulation upon the central nervous system. These spontaneous contractions are not dependent upon voluntary control and they may be found even after removal of the organs or part of the organs from the body. It is for this reason that the plain muscle has been called involuntary although this term is not entirely satisfactory because some of the smooth muscles are subject to the influence of the will as the ciliary muscles in connection with the eye and some striped muscles are entirely out from the control of the will as in the case of the cardiac muscle. The smooth muscles are found to manifest the same electrical properties as striped muscles being very sensitive to the opening and closing of the constant current, hardly responding at all to an induction shock, possibly because the duration of the current is too short. The muscle contraction in the case of the unstriped muscle is very slow and much prolonged even when it originates from a strong single stimulation. Some claim that this indicates the possibility of tetanizing the smooth muscle. Foster says that the smooth muscle tissue can be tetanized although it rarely takes place. The same object is secured in the plain muscle as is accomplished in the case of the striped muscles by tetanus, by means of the tonic constriction of the unstriped muscle. The smooth muscle can remain for a long time in a contracted state this representing the tonic condition.

CHAPTER XI. THE NERVOUS SYSTEM.
SECTION I. Introduction.

The physiology of the nervous system is dependent for its elucidation, (1) on the anatomy of nerves in their origin, course and relations as well as the development of these in the animal history; (2) on the histology of nervous structures particularly studied in connection with the different stages of development from the embryo to the adult condition; (3) on clinical experience and pathological observation which have emphasized changes due to disease and abnormal conditions; (4) on experiments in connection with the division and stimulation of the divided nerves which have in recent times furnished a mass of evidence that emphasizes the functions of certain nerves and indicates, if it does not entirely prove, the relation of certain nerves to organs and other nerve channels. For a long time anatomy and pathology were found to be the only evidence. When the nerves were found to terminate in muscles they were supposed to be motor; those in connection with the organs of sense were supposed to be sensory nerves. The cerebral enlargement found in the higher animals as compared with the lower animals was supposed to be connected with the psychic development of the human subject. In later times experi-

ments in connection with the nerves divided have opened up many new facts in regard to the nerve centers and also the different nerve paths. In connection with surgical operations by the dividing of nerves it has been found that parts cut off from the higher centers lose sensibility and the compression of certain centers resulted in paralysis. If to these are added histological observations as to the structure and course of certain nerves there is a very complete knowledge gained of the function of the nervous mechanism.

In the embryo the central nervous system arises from the epiblast. The white and gray matter of the spinal cord and the brain originate from the medullary infolding. The sympathetic system, including the nerves and ganglia connected with it towards the periphery, also arises from the epiblast. This epiblastic layer also gives rise to the sense organs, the organs being expanded in such a way as to become specialized in the reception of impressions of a definite character. These sense organs therefore originated from superficial cells which under the influence of certain definite stimulation and by continued use in connection with certain stimuli have come to be specialized in function. These specializations become the centers of organic functions communication being established with neighboring cells these terminals of communication being differentiated as special nerve paths. This course of evolution may be followed distinctly in the field of comparative physiology. In the Actinia we find no organs of sense and no central system although there are found cells distributed in the cuticle and in the alimentary ~~with~~ canal hair-like processes on both sides, the internal and deeper forming plexuses in the substance and constituting neural structures. These represent sense cells some of which have been moved internally. In the medusæ we can trace the movement from nerve epithelium in the primitive cell form to the ganglionic center, two kinds of cells being found; (1) a primitive cell in which we find minute hair-like processes extending outward to the superficial part of the body called sense processes and also processes passing inward to the ganglion cells; (2) a modified cell in which the hair-like process corresponding with the sense process is lost and the regular cells have been developed. In this way from the stand point of evolution and embryology the entire central nervous system arose from the modified sense cells, the connection of muscles being of later development, the processes from these sense cells forming the primitive nerves. It is only in the higher forms of life that we meet with muscle connection complete in connection with the nerve fibres. This connection between muscle and nerve is supposed to be established by the relations established between neuro-epithelial and myo-epithelial cells so as to form neuro-muscle plates. The nervous system in the human subject developed by evolution out of the epiblastic layers, when fully developed, is found to consist of three parts; (1) ganglia representing the masses of the brain, spinal cord and the ganglia connected with it; (2) terminal organs or plates found in connection with the sense organs and the muscles, and (3) the nerves or nerve paths connecting the end organs with the central nervous system. These nerves are paths along which nerve forces travel, the force originating in the end organs or in the nerve by stimulation or in the nerve centers. Stimulation applied to the nerve path along its course gives rise to irritation which passes along the nerves to a center or an end organ, resulting in the production of certain phenomena of movements, feeling, sensation, etc. Stimulation may originate in an end organ, the stimulation being

transmitted along the nerve carrying the sensation or a change resulting in action, movement or feeling of some kind. Similarly stimulation may arise in the center or centers, the impulse being conveyed along the nerve paths terminating in the muscle and producing some kind of action. The fibres of the cerebro-spinal nerve are bound up in a sheath of loose connective tissue. The epineurium sends down divisions into the internal of the nerve dividing the nerve into bundles, the nerve fibres being bound in minute folds, all these coverings being continuous with the connective tissue of the external perineurium. The fibres do not divide except near certain terminals, although the fibres from neighboring trunks join and become closely bound together.

In the sympathetic system the fibres are mostly non-medullated and hence are much brighter in color than the cerebro-spinal fibres. In the large nerve trunks there are capillaries together with lymph spaces found in connection with the epineurium and the perineurium. Along the path of the nerves there are groups of ganglion cells found either in rounded masses or elongated fibres. Around the external surface of the ganglia there is a covering, the continuation of the epineurium consisting of loose connective tissue. In these ganglia we find large numbers of minute capillaries, these capillaries surrounding the cells in order to carry on the active nutrition of the nerve tissue. In the cerebro-spinal system the ganglia have large ganglion cells each cell being surrounded by flattened endothelial cells. If the nerve fibres enter the ganglia medullated they lose their medulla and issue from it non-medullated. In the sympathetic system the ganglion cells are smaller and multipolar as distinguished from the unipolar cells of the cerebro-spinal system.

In the gray matter we find both fibres and cells so that these cannot be separated on the application of stimulation. The stimulation of the gray matter depends largely upon the supply of blood and also upon the rapidity with which the waste matters are taken away. If the blood supply is not sufficient or if the carrying away of the waste product is incomplete then the nerve cells become inactive or suffer through lack of proper nutrition. If the blood supply is cut off suddenly the change is so sudden that it produces unconsciousness. Similarly the absorption into the blood of chloroform, alcohol or ether will induce unconsciousness. In many diseased conditions the blood becomes so vitiated that it is incapable of carrying on the vital functions, the result being some form of delirium. The nerve cells thus depend on the normal activity of the blood supply and on the favorable conditions involved in the equilibrium of the various centers, the disturbance of this equilibrium resulting in abnormal conditions. There is a rhythmic action in connection with the nerve cells and centers, this rhythmic action depending on blood conditions as is indicated by heart and respiratory rhythm so that any interference with these involves an interference with nerve center activity. The gray matter consisting of nerve cells forms the chief part in which reflex centers are located and these are connected with one another by nerve fibres. Sensations involve consciousness in connection with an impression these impresions made upon sensory nerves being conveyed to the nerve centers. Often stimulation produces movement indirectly, the impressions passing along nerve paths to a center from which certain impulses are passed to other organs or muscles by nerve fibres. If the brain and medulla of a frog are removed and and if stimulation is applied to the foot the limb will be drawn up. This

is said to be due to reflex action, the reflex taking place without consciousness. In the nervous system as a whole we find a number of contiguous nerve cells united together so that nerve function depends on the establishment of this relation and its maintenance so that the continuity of the nervous system is the basis of its functional activity. When therefore the nervous system is spoken of as consisting of a central and peripheral system this division is simply for convenience of consideration. In connection with the nervous system the relations are established between all parts of the body, its branches following the form of the body representing pathways and centers in connection with which organic activity and unity are maintained. All impulses must reach the central system before a resulting outgoing impulse can be sent out. On account of the very extensive connections of the nervous system and the centralizing force of the central system harmony is established in the body organism. It is in connection with the nervous system and particularly the central system that the facts of consciousness arise. Strictly we limit ourselves here to the nervous system and the functions that are independent of consciousness, although we can not eliminate the psychic element of brain control from the functioning of the entire neural mechanism. We leave to the subject of Psychology the more full discusson of the conscious side of the neuro-physiological life.

The progressive development of the nervous system with its subdivision into faculties has its most perfect expression in the human brain. This localization is brought out in connection with spoken language, voluntary motion, sight, etc. Excitation literally means to call from the outside so that the external surroundings of an organism stimulate it so that the organism receives, records an impression and thereby modifies its movements. The central nerve cell is really a double organ one portion of which is at the central end of an afferent nerve fibre and the other portion at the central end of an efferent nerve fibre, so that there is a sensory and a motor part in the center, the two parts being bound together by commissural fibres. We have seen that automatic and reflex actions characterize the lower central cells, voluntary action on the other hand characterizing the higher cells. The voluntary actions are spontaneous and are subject to choice, independent of stimulation; and yet we can not deny that voluntary action is really a complicated reflex action with the stimulation more or less disguised in the past stimulations of the organism. No line of differentiation can be drawn between these two forms of the voluntary activity. It is claimed that the higher scale of voluntary action represents the psychic elements of discrimination and imagination as distinguished from the pure sensation and motion elements, although the simplest voluntary contraction implies a sensation, a comparison and judgment and a voluntary motion. The characteristic of voluntary action is determined by the past history of the individual impressions. From the purely physiological standpoint the element of time is the determining element, because in a purely reflex act the reaction is immediate; in an automatic action the motor reactions represent a series and in the voluntary action the reaction is retarded. The voluntary act then, from the physiological standpoint, seems to be explained on a basis of past impressions so that it is the result of these prior sensations; so that in the cerebral activity the characteristic action is delayed for the purposes of judgment and deliberation. The importance of cerebral control as compared with spinal control is determined by the scale of the

animal intelligence, the higher the scale the greater the cerebral importance and the less the spinal, so that in the ascent of the scale of intelligence the cerebral functions are becoming more significant and the spinal less significant. From this standpoint Waller claims that the spinal cord represents the conservative organ and the cerebrum the progressive organ.

In nerve cells which are found in the gray substance we find irregularly circular bodies composed of fine granular matter with a large nucleus and nucleoli. In addition there are often found pigmentary substances buried in the cell substance. In the sympathetic ganglia we find smaller cells from 10 to 20 mm. in diameter, such cells we find in the posterior cornua of the spinal cord and in parts of the cerebrum; larger cells are found in the medulla and cerebellum from 40 to 60 mm. in diameter and the largest cells in the anterior cornua of the gray matter of the spinal cord up to 130 mm. in diameter. In connection with the nerve cells we find processes which shoot off from the nerve cell body of the same substance as the cell. Different processes are found in different parts of the system. In connection with the Casserian ganglion and the spinal ganglia in the human subject we find a single nerve process; in the sympathetic ganglia the cells have several processes while in the gray matter of the brain and spinal cord there are from three to eight processes which shoot in different directions; when they pass from the cell a division and subdivision takes place ramifying finally into fine filaments. Sometimes the process remains undivided for a considerable distance. The nerve cell is encased in a capsule which consists of a fine colorless membrane covered over on the internal surface with nuclei. Normally the capsule is almost filled by the cell. The process as it passes out from the capsule is accompanied by an elongation of the capsule in which the nerve process is encased. The nerve fibres are united at the point of central origin with the gray matter into which they pass between the cells. It is not easy to separate the fibres and cells because when dissected there is apt to be a tearing of the relations. In any case it is clear that the nerve process is continuous with the nerve fibre, at least in most cases, so that this continuation represents the connection between fibre and cell. The cell process is so like the axis cylinder of the nerve that it is very difficult to distinguish between the two. In some cell processes however there is a junction with nerve bundles without any medullation so that they become non-medullated fibres, the tubular elongation of the capsule being continuous with the sheath of Schwann. In the cerebro-spinal ganglia of the rabbit and the spinal ganglia of the frog the myelin layer has been found almost up to the cell itself. These facts indicate that there is a close relation structurally between the axis cylinder of the nerves and the processes of the cells. In connection with the nerve cells in the brain and spinal cord of the human subject the multipolar cells have certain processes which unite with the groups of fibres running towards the nerve roots so that the processes become nerve fibres although they are not surrounded by the medullary substance. It is claimed by Gerlach that there is a portion of the gray matter of the cord in the dorsal region in which the nerve cells have no process corresponding with an axis cylinder and in the sympathetic ganglia the cell processes pass for a considerable distance without being fused into a medullated nerve. This may indicate that some of the cell processes do not pass into and unite with the nerve fibres. These nerve cells embedded in the gray substance form the

nerve centers in connection with which the impressions are received along the sensory nerve fibres and from which excitation passes to the muscles along the motor fibres. These collections of cells and the gray matter correspond with the nerve centers representing the nerve apparatus in which transformation and modification of impulses takes place. Thus we have in all the nerve relations of the body organism a complete circuit established as the basis of impressions connected with sensation and movement.

SECTION II. The Evolutionary Development of the Central Nervous System.

It is almost impossible to appreciate the functions of the central nervous system without tracing the development from simple structure to complex structure and from simple to complex function. Among the invertebrates we find nervous systems consisting of ganglia or chains of ganglia; whereas among the vertebrates we find nerve tissue formed into a spinal cord and terminating in a brain with a distinct cerebro-spinal axis. This is the only way to get an adequate idea of the nervous system in following out its changing form in the scale of animal life. In the most primitive animal forms of the nervous system we find the cell of protoplasm forming the center of activity in connection with motion and sensation. As soon as the cell coatings become numerous and independent of each other sensation becomes associated with the external layer. As soon as the sensory system becomes of importance to the organism parts of the sensory layer enter into the body or deeper structure of the organism, the outer parts becoming differentiated as ganglia as well as the inner; the superficial parts representing the organs by which connection with the external world is established, this connection being transmitted by impulses into the deeper parts or ganglia by means of processes communicating from the external to the internal. These processes from the internal to the external pass into communicating fibres. The forming of the nervous system follows the structure of the animal, for example, in the star fish the nervous cord is symmetrical with the body arrangement, the neural arrangement being in line with the structure of the body. For example, the sense ganglia become enlarged and more important as the sense organs develop. As the body becomes more complex the nervous arrangement is more complicated, the cord and ganglia being arranged from the different portions of the body, these being arranged together by a central cord or chain of ganglia. Next the ganglia are united together into masses, the combination depending upon the value of innervation to the body and the portion of the body supplied. In the vertebrate the enfolding of the epiblast originates the nervous cord that forms the cerebro-spinal axis. This primary cord is widened at the upper end and then subjected to constriction, and this forms the three cerebral portions or vesicles which form later the anterior, middle and posterior portions of the brain.

This primitive cord appears in tubular cavity form, the tubular cavity becoming the spinal canal and the thickened portion representing the brain; the spinal cord in its tubular cavity representing the embryonic tubular condition of the nervous matter. The three cerebral portions bormed by loops are called the fore, mid and after brain. From the anterior loop there is formed by protrusion, first a single part and then

double parts divided by a median line, representing the hemispheres which are separated from one another by the median line. The prolongation of the cavity into the brain represents in the adult condition the lateral ventricles. Out of each of these vesicles there arises by protrusion the olfactory lobe, the remainder of the hollow cavity of the vesicle becoming the third ventricle. At the outer and lower walls of the hemispheres there are thickenings which correspond with the corpora striata, two bodies represented on the floor of the lateral ventricles, the upper part on the roof being developed into the cerebral hemisphere substance. Right behind the corpora striata on the floor of the third ventricle there are two thickenings of the circumferential wall which become the optic thalami, the fine layer lying between the two being called the taenia semicircularis; the hollow tubular cavity forming the cavity between the thalami to the cerebral cavities being called Monro's foramen or the opening under the arch of the fornix. The floor of the third ventricle is posteriorly formed by the tegmenta of the crura cerebri being formed into a conical process at the end of which is the pituitary body. The roof of the cavity is delicate being limited by the anterior and posterior commissures, the pineal body being developed in connection with it. From the one corpus striatum to the other there pass fibres which form the white commissure, the gray commissure connecting the two optic thalami. The corpus callosum by the commissural fibres connects the two cerebral hemispheres, in highly developed brains it crosses considerable higher than the level of the fornix, intercepting a part of the internal wall of either hemisphere. The two internal walls form the septum lucidum, the space between constituting the fifth ventricle cavity. When the floor of the middle loop thickens there are formed two large groups of longitudinal fibres forming the crura cerebri, the optic lobes, corpora quadrigemina being developed on the roof. The tubular cavity is represented by the Sylvian aqueduct. The third loop in its development remains practically unchanged as compared with the other two loops. On the upper wall we have a very fine surface anterior to the cerebellum, forming a lamina, the posterior part being covered with membrane and opening into the posterior sub-arachnoidal cavity. The cerebellum first appears as a fine medullary lamina representing the thin Vieussens leaf between the cerebellar processes to the brain, the posterior part being covered with delicate membrane and connected with the space that lies ender the arachnoid membrane. The cerebellum arises in connection with a delicate medullary layer arched posterior to the corpora quadrigemina, the epencephalon forming the cerebellum, pons Varolii and the frontal portion of the fourth ventricle, the metencephalon forming the medulla oblongata.

The complexity of the structure of the brain of the higher animals arises from the greater and the increased development of the cerebral hemispheres, and very early in the progress of the development of these hemispheres there is a projection forward beyond the primitive first loop. As they develop upward they take the place of the second loop filling up the most prominent portion of the head; as they develop downward and to the sides they constitute the temporal lobes. In this way we have the distinct development of the frontal, parietal and temporal lobes. Still later by the posterior development the occipital lobe it forms the completed cerebrum so that it occupies a position high up in the head and covering entirely the lower portions of the brain. Thus the hemispheres enlarge from the small loops of the early embryonic brain in the animal until they

occupy a position above all the other portions of the brain in the human subject. During the progress of this development the superficial gray matter enlarges to such an extent that it is thrown into an immense mass of convoluted furrows. The superficial surface of the hemispheres is primarily smooth, the first division being noticeable between the temporal and frontal lobes in a rough indentation, afterward developed into the Sylvian fissure. Later we find the separation of the occipital and parietal lobes taking place in connection with the vertical fissure and the frontal and parietal lobes by the fissure of Rolando. This development marks the highest animals next to man and man himself. It is after the formation of these dividing grooves that the convolutions begin to form, first by the formation of shallow and indistinct furrows marked at birth in the human subject. Later these are represented by the deepening of these furrows and the continuation and extension of the process in the formation of subordinate furrows after birth. It is in connection with these convolutions that psychic development takes place, the greater the psychic development the more marked the convolutions become. Arising from the same characteristic type we find the brain development in the animal kingdom becoming gradually more complicated; the brain found in the lower animals when complete, as in fishes, reptiles and birds, corresponding with the lower stage of development in the higher animals. Among the fishes, for example, the brain retains its embryonic characteristics consisting of a number of protuberances either in pairs or singly. In some of the lowest forms, as in the leptocardia class of fishes, there is no brain proper, the cord being continuous without any enlargement. In the cyclostomata we find the development nearer the primitive embryonic form of the higher animals as the five characteristic portions of the brain are distinguishable, the chief development being in connection with the ganglia that represent the sense organs, the cerebrum being very imperfectly developed. In higher forms, as the skate and the whole class of teleostomi, the cerebral part of the brain is developed, the lobes of the brain being characteristic, especially the optic lobe in connection with sight, and the medulla being large. Among the amphibia the two hemispheres are fully developed, while in other forms the cerebellum is distinctly marked although small. Among the reptiles the posterior part of the anterior embryonic vesicle and the mid-vesicle are very fully developed, while the anterior portion of the brain is large and developed backward over the lower parts of the brain. Among the birds the hemispheres of the cerebrum are fully developed, the middle brain vesicle being concealed beneath the hemispheres and are connected together by an anterior commissure. The cerebral hemispheres are found to contain a large quantity of cerebral substance which is projected into the ventricular cavities. The middle part of the cerbellum is arranged in layers of gray and white matter. There is not found the pons Varolii, the fornix or the corpus callosum, but there is a mass of matter arranged in ganglionic form corresponding with the corpus striatum and the optic thalamus, the optic lobes representing advanced development. Among the mammals the cerebral hemispheres are very fully developed being connected by the corpus callosum. This commissure is small and is limited to the anterior portion of the hemispheres in the marsupialia like the opossum; in the lower animals it extends to the posterior portion, this extension marking the advance in development as we rise higher. The hemispheres in the lower animals are not large, have no lobular division and few if any con-

volutions. The eemispheres extend posteriorly over the cerebellum and medulla. The posterior lobe is developed and also the anterior lobes throwing the cerebrum forward into the forehead; the internal brain development becoming more complicated, the anterior and posterior lobes being united in connection with the fornix. In the transition to the higher orders we find lobular divisions and the frontal development of the cerebrum. In the higher mammals the superficial surface of the brain becomes convoluted, the convolutions varying considerably in different animals. No regular order of convolution development can be marked in the different grades of animals; for example, in the marmoset, or squirrel monkey of South America, there is practically no convolution development, while in the ordinary monkey the brain is very abundant in convolutions. The cerebellum also becomes more complex from the lower to the higher animals; originating in a simple layer in the lower animals, as in the fishes, it becomes definitely marked in the transition to the divided portions constituting the lobes. In the crocodile, for example, it is clearly differentiated, and in the birds there is a triple differentiation, the middle being larger, while in the higher animals the lateral parts are larger. In the spinal cord there is not much variation among the different animals. In the center of the cord is found the gray matter surrounded by white matter, the gray being most abundant where there are areas connected with limbs. In the higher animals the cord can be divided into distinct columns. The mass of the cord depends upon the nerves that branch from it, being largest in the region of the limbs in the higher vertebrates from which the limb development takes place. The development of the cord is marked distinctly in regions representing the cervical, dorsal and lumbar areas. The enlargement of the brain in development corresponds somewhat with the developing mental capacity of the higher animals. Allen Thomson, who is one of the greatest authorities on craniology, says that cranial capacity is larger among the civilized than among the uncivilized races; and even among the civilized there is a noticeable difference between the educated and intelligent compared with those of average or inferior mental capacity. In the case of the ape the brain is much inferior to that of man in weight and size. The gorilla brain is less than one-third and the orangoutang brain less than one-fourth of the weight of the human brain.

In the ape and gorilla the brain is about .01 part of the body weight, while it varies in man from one-fortieth to one-fiftieth. At birth the brain of a child is about one-tenth of the weight of the body; at three years the brain has developed to about three-fourths of the adult size of the brain; at the close of seven years of age it has developed to about nine-tenths of its regular size, the other one-tenth being slowly developed from seven to 25 years of age. In connection with this brief embryological account of brain evolution it is to be noted, (1) that the principal part of the cerebro-spinal system from the standpoint of development is the medulla and the spinal cord. This portion of the nervous system is found among all vertebrates and constitutes the nerve basis of locomotion, respiration and even mentation on its lower basis, together with the tactile sensations which are fundamentally the most primitive of all the senses. (2) In the differentiation of the higher centers certain parts of the frontal region of the cerebro-spinal system are developed and differentiated, the development taking place always posteriorly and downward. The first development in this direction is the sense of vision, hence the vision de-

velopment in connection with the optic lobes marks the lowest form of animal life in which the senses are differentiated. Following this we have the development of the region of the optic thalami specialized in connection with the sense of touch or at least the general tactile sensations. The sense of smell is localized in the anterior part in close connection with the prosencephalon, indicating that it makes its appearance as one of the first special organs; thus smell vision and touch are the three primary centers, so called because necessary to the primitive physiological existence. These three centers are closely connected with the same cerebral region in primitive development. The auditory region from which springs the auditory nerve is located in the medulla indicating the early character of hearing in close connection with the oblong marrow, representing the expansion of the spinal cord in connection with the earliest coordination of impulses in relation to movements and body equilibrium; similarly the sense of taste originates in connection with the medulla from which arise the gustatory nerves, the deglutition processes originating from the same region. All of these represent the primary acts necessary to physiological existence. (3) Following the differentiation of the different senses and the different sensations connected with these senses we find the origination and development of ideas representing psychic changes, corresponding with mental phenomena of judgment, memory, emotion, volition and intellection. The cerebrum being more fully developed according to the mental phenomena manifested by the animal life, the mental condition is proportionate to the brain development. We find a gradual increase in complexity of brain structure and function as we markthe increase in intelligence; as we advance from the lower to the higher animals the brain becomes more complex. The prosencephalon is regarded as the portion of the brain in which mental capacity and activity are localized, this part of the brain representing an enlargement commensurate with intellectual development. (4) Connected with the cerebellum development we find the coordinate movements of the different parts and organs of the body. These movements vary considerably in animals from the fish up to man, representing different stages of development from the simple back and forward movement of the fish in connection with their fins, to the rotary movements of the birds wing's, up to the delicate movements of the front limbs in the human subject. The development of the cerebellum from the simple to the complex represents the adjustment of these coordinate movements to the special form of animal life. Cerebellum development marks particularly the high degree of development found in man. As we have seen in the human subject each part of the cerebro-spinal system represents a marked improvement upon the lower forms of life, the characteristic high development of the spinal cord, cerebrum and cerebellum, indicating the final point of perfection reached in the case of the highest of all animals, man. This is in line with the complexity of the bodily system as found in man and also the psychic conditions represented by intelligence, emotion and will by which the vegetative functions are discharged in the maintenance of life both individual and species, and also the animal function by means of which he is conscious of a world outside of himself and brings himself into conscious relation with this outside world. Thus it is the nervous system in man in all its complex bearings that places man at the head of all species of creatures, endowing him with preeminent glory as the climax of all development. But he is not only the culmination of development, he repre-

sents all the lower stages in his own development from an embryonic to an adult condition, so that all the perfection of neural mechanisms in animal life contributes to the perfection of the human neural mechanism.

The human nervous system is continuous throughout the entire system, the nerve tissue consisting of minute nerve cells all arranged together to form a united system. In the division of the nervous system into parts, therefore, the analysis is artificial and the anatomical separation has no physiological significance except in tracing and emphasizing connections. The continuity of the nervous system is the means of uniting all the different parts of the body, the impulses being carried along the different nerve paths with the result of uniting these parts in harmonious action and continuous activity. In addition to the unison of all the parts an important factor is found in connection with this other fact, that all impulses must travel to the central nervous system. As we have seen in the development of the nervous system from an immature to a mature condition the increasing evolution of the parts and of the whole nervous system goes on side by side with that of the complete organism of the system so as to complete the connection of all the parts. The connections become also more delicate and are more freely and firmly established so that relations that formerly werei mpossible become perfectly natural. The increased complexity of the system, therefore involves the greater efficiency of the nervous mechanism and its better adaptation to the functional activity. This adaptability implies the possibility of so regulating the development of the system as to make it capable of doing what otherwise under different conditions it would not do. It is here that we come to the realm of consciousness and enter the field of conscious development, for while physiology alone is the science with which we deal in discussing the nervous system, it cannot be forgotten that psychology explains many of the physiological phenomena and particularly the modifications taking place during physiological development, which results in a higher nervous condition than that found apart from consciousness. By the study of development in connection with the central nervous system we are able to find out the arrangement and structural value of the different parts of the system and by the comparison of the different parts as found in different grades of animal life we are able to find out the physiological functions belonging to different parts of the system. Development is especially of value in enabling us to follow out the different paths into which the white matter of the central system is divided. The medullation does not take place in all the parts at the same time, for example, the pyramidal tract is found to be non-medullated at birth.

Very early in the development of the vertebrate existence the neural canal is found as a furrow in the epiblast in connection with the blastoderm. The sides of the medullary furrow develop internally until coalescence takes place when the canal is completed. After its completion the anterior portion expands in the formation of the embryonic vesicles so that throughout the entire central system there is a tubular canal in connection with the cerebro-spinal axis. This primary canal continues in the adult condition representing the ventricular cavities of the brain and the spinal canal in the spinal cord. It is in connection with the walls of this canal that the cerebro-spinal axis is developed and also the roots of the anterior spinal nerves. The spinal ganglia originate in connection with a number of epiblastic enlargements which are found developed along the

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external walls of the neural canal. The ganglion cells are bi-polar so that from each pole there is developed a cell process, one peripherally and one centrally, to bind the ganglia to the cord. In connection with the posterior brain vesicle is developed the pons and cerebellum, in connection with the mid-vesicle the corpora quadrigemina and the crura, while the fore brain gives rise to the third ventricle and the optic thalami. Later a secondary fore brain vesicle is developed anteriorly in connection with the roof of which the cerebral hemispheres are found and in connection with the floor the corpora striata and the olfactory lobes. In connection with this secondary fore brain there is the formation of the optic vesicles on each side of the fore brain, a portion of the epiblast developing into a lens producing an indentation in the nerve substance, the concave part of which corresponds with the retina and the convex with the choroid, the branching proces representing the optic nerve. In the development of the central system we find the nerve elements in connection with the fibres and cells, the essential portion of the fibres being the axis cylinder that is projected as a process ot the cell, medullation being a result of the active development of the axis cylinder process. The nerve cells represent the most important part of the neural substance and they are found closely packed in the cerebral substance, the basal ganglia, sympathetic and scattered ganglia of the organism. In the branching of the processes of these cells the processes become woven together in the formation of the charateristic plexuses which next to the grouped cells form the most important element of the neural substance. The connective tissue of the central system consists of ordinary connective tissue originating from the mesoblast and of the neuroglia that arose out of the epiblast. The entire cerebro-spinal axis is encased in four concentric sheaths, (1) Close to the cavity of bone in which the substance lies is the dura mater; (2) close to the neural substance the pia mater which corresponds with the brain convolutions and cord fissures furnishing the vascular connection to the nerve tissue; (3) between the outer and inner sheaths is the double arachnoidal membrane divided from the pia mater by a layer of cerebro-spinal fluid. Running out from the pia mater are processes that constitute the framework of the non-neural substance, the interstitial parts being filled in with branching filaments from the neuroglia cells. In this way solidity is given to the neural substance.

SECTION III. The Physiology of the Nerve Cell.

In dealing with the nervous system the plan to be followed is, (1) a discussion of the nerve cell in order to understand how this unit element in the nervous system acts physiologically. (2) A discussion of the combination of nerve cells in the system as found in groups, because here we have the basis of connected activities on the part of the neural elements. (3) A discussion of the neural system taken as a whole, in which the distinctive functions of the nerve mechanism are discussed.

The nerve cell consists of a cell substance including the nucleus and cell branches. These nerve branches may be prolonged so as to form nerve fibres or they may be shortened simply forming protuberations and branchings. The nerve cell includes the cell substance and its branches or processes together subject to the control of the nucleus. There are great differences in the nerve cells, the branches varying and also the shapes of the cells. In the main cells there is a cell body and one princi-

pal branch called the neuron in relation to the cell body from which it is an outdevelopment. The cells from this standpoint are sometimes arranged according to the number of their branches, mononeuric, dineuric. In connection with the neura we find also subsidiary branches coming off at different parts of the process. The branches often assume a complex appearance in the form of branches from a tree trunk and are hence called dendrons. The cell is normally oval in shape although it is subject to much variation, the diameters of these cells varying from .01 to .1 of a mm. In connection with the cell substance two elements have been found, the one constituting a stroma which is continuous with the minute fibres of the nerves and the other a granular mass enclosed in the meshes of the stroma. These granular masses are very subject to stimulation, indicating the variation that takes place in connection with nerve irritation. These nerve cells are large compared with the other tissue cells of the body, the nucleus being small, decreasing as the cell enlarges. The chief characteristic of the cell is the extent of the development of its principal branch, the neuron, which is the enlargement of the cell substance, these branches, varying in certain cases from 50 to 100 centimeters in the central and peripheral systems. Some of the neura are short where the cell body passes quickly into the smaller branches. When the cell body is estimated volumterically, for example, the pyramid cells found in the cortex cerebri are found to contain about 4,000 cubic micra, the volume of the cell neuron varying according to the length of the branch and its diameter. The dendronic branches also vary considerably, none being found in the spinal ganglia while in the cerebellar cells they are larger then the cell body in volume. The minute subdivisions of the branches represent a larger volume than the cell body. The cell body and the branches vary in different animals being larger proportionately in man than in the lower animals. In the smaller mammals the cells are small although not proportionately to the size of the body. This is due to the simple structure of the nervous system in the lower animals as compared with man. In smaller animals the neuron is not of the same length as in larger animals so that the diminution corresponds with the body. The cells including the neura are found to be quite large in small animals, yet as the nervous system is less in size relatively there is a diminished number of cells.

In the human subject these large cells represent a great number of living elements in which we find stored up energy, this stored up energy being found in connection with the cell substance and being liberated under stimulation. When these large cells branch very abundantly we have connection freely and fully established with the surrounding tissues and organs indicating not only large energy capacity but also large distributing power in the case of such energy being liberated. The cell extends out into branches that divide up into dendrons and neura, so that the cell contains a large proportion of tissue elements capable of metabolism, so that as the cells are larger the metabolism is increased. These large cells have therefore an abundance of material and also free connections with the tissues of the body as branches so that the larger the cells the greater the influence exerted on the system. The elements of these nerve cells arise from the germ cells in the embryonic epiblast, the spherical cells being found about the third or fourth week of the embryonic life, the germinal cells dividing in the formation of new cells; one of the new cells takes the place of the old and the other migrates further from the

surface so as to form a neuroblast. This neuroblast formation goes on in the embryonic life for about twelve weeks, these neuroblasts being at first migratory cells possessing characteristic amœboid movements. These movements are determined by the principle of cellular attraction and repulsion, their position after the close of the fœtal life in the adult determining the character of the tissue. In the early stages of neuroblastic growth the cells become polarized, that is the point of neuron growth becomes fixed and the direction of neuron growth established so that no variation takes place afterwards. When the cells after development become mixed, the neuron not occupying its proper position in the developmentof direction we find an arrangement such as exists in the brain of congenital idiocy. During the development of the nerve cell we find in addition to the neuron polarization and growth, the formation and development of the dendronic branches, together with enlargement of the substance of the cell and the neuron and the chemical change that takes place in the cell substance, these changes taking place at variable periods in the life history. In the classification of the cell the neuron is the most important element. The physiological value of the cell in its relation to the nerve impulses is that it constitutes a channel for nerve connection. When the impulse enters a cell it travels through it and along the neuron. In the primitive cell all the different branches performed this function, for the stimulation of a part of the cell or of its branches established communication with the entire cell, the entire cell giving a response.

In the formation of the branches they become therefore nerve paths along which impulses pass usually entering along one branch and passing out along another branch or other branches, at least in the fully developed cell. In the human subject we find two varieties of these branching cells, the one in which numerous branches arise both in connection with the neuron and the dendronic divisions; while in the other we find simply two neura arising out of the cell body, these branches being medullated and running in opposite directions, no dendrons being found. These can only be followed in connection with their evolution. In the last case the cell must have been bi-polor each pole giving origin to a neuron. In connection with the cells of the spinal ganglia there is only a single neuron with double branches; from each pole arises originally one neuron the cell body falling to the side of the two neura the two passing into one another, while the cell body is divided from the single neuron by a fibre from which the two neura pass as branches. It has been inferred that two fibre paths are bound up in the single branch representing the spinal ganglia and the cells found in the cortex cerebelli, the single branches having a two fold function of leading out and taking in the impulses to cell body.

This gives us two classes of these cells, (1) those in which we find a single path. Primitively the cells had two neura at each pole but these in the evolution of the cell have been connected together in the same branch, a stem being developed which unites them to the cell body, the impulse passing in and out along the same branch which represents a double pathway. Here there are no dendronic branches. (2) We have the cell which has a neuron and various dendronic branches, the impulses generally coming in by the branches and leaving along the neuron. These represent the spinal and pyramidal types. When the characteristic type of cells has been developed there is a continuous development in size on the part of the branches, the diameter increasing to four or five

times its original size. In the neuronic branch we find an axis cylinder encompassed by a medullary sheath. Two opinion have been advanced as to the origin of the axis cylinder; the first is that the axis arises out of minute filmy fibres moving inside a peculiar plasma that coagulates around the fibres, the fibres being the nerve impulse conductors. According to the second view there is a spongy stroma intermingled with a semi-liquid plasmic substance out of which the axis cylinder is formed. According to the first theory it is claimed that we have an explanation of the different kinds of fibres found within the same nerve: but these minute fibres do not pass through the sheath without branching as these fibres become divided at least towards the peripheral ends, these branches being too numerous to permit of believing that along the whole path these isolated fibres range unbroken. According to the other view the impulses pass through the plasmic substance. On the other hand if the axis cylinder consists of a series of minute tubules formed amid the meshes of the spongy stroma at varying angles, the anastomosis will be so frequent as to prevent the possibility of regarding the pathway of impulse as isolated and continuous along the entire axis cylinder path. As the axis cylinder becomes enlarged these minute tubules are increased, as it derives nutriment along the whole course of its path and not simply from the cell substance at the one extremity. When the branches of the cell have developed then begins the formation of the medullary sheath. The neura are not all medullated and the medullation is not complete ~~in many~~ in any neura. Both in the sympathetic and the cerebro-spinal systems we find numbers of unmedullated fibres. The physiological value of this sheath is unknown, although it is suggested that it isolates the fibres within the sheath so as to preserve intact the channel through which the nerve impulse passes, thus preventing a break in the impulse communication. Others think that it exists for trophic purposes in order to sustain the normal nutrition of the nerve fibre. It has been found by the application of stimulation that certain fibres lose their irritability and their power of conductivity at the point where a strong electric stimulation is applied. This is particularly so in the case of the vaso-constrictor fibres. This only occurs where the fibres are unmedullated. The medullated fibres are originally non-medullated and it is claimed that medullation represents the highest point of development in the case of the nerve cell and its branches. In proof of this it is said that some of the fibres do not attain to their functional activity until they become fully medullated. It is a question, however, whether this depends upon medullation or on the establishment of connection with other tissues, this connection being supposed by some to be the basis both of functional activity and medullation. By establishing connections with the branches of other cells or with the tissues a pathway for the passage of the impulses is opened up and in this way the fibres become active. This connection, however, is established in the case of the non-medullated as well as the medullated so that medullation does not necessarily determine function. Wherever medullation does take place the sheath is formed before the maturity of the nerve fibre. In the peripheral parts medullation is determined by the existence of certain nerve cells that form an encompassing sheath around the nerve fibres, the various cells being regulated by nuclei about the center of the cell substance. The point of connection between the cells represents a node in the nerve fibre. The sheath becomes thicker as the axis cylinder develops, the portion between the axis and the sheath being maintained in

the gradual development. As the fibre grows the distance between the notches also increases. These nodular segments represent the trophic centers, the many nodes indicating the conditions in favor of proper nutrition in the normal interchange between the fibres and the plasmic substance. The nodes represent the points at which the axis cylinder receives its nutrition hence where the nerve fibres are more active these notches are more numerous. In the central system medullation takes a longer time to complete as compared with the peripheral system which is completed before the end of the fifth year, while in the central system particularly in the cortex cerebri the process goes on from 30 to 35 years. No medullation is found in connection with the neuron when it is found in the embryonic condition of the cell, medullation taking place all along the fibres at the same time.

The medullated sheath is not found on the neuron close to the cell or in connection with the branches when distributed in tissues, the sheath representing therefore the physiological function in connection with the middle portion of the nerve fibres. The medullation therefore is not progressive but represents complete development. Some of the branches of the neuron are also medullated, this taking place when the branches form their connections the medullation representing complete development. During the progress of these changes in the neuron and the branches the cell body is also changing. The chromatic substance in connection with the cell substance becomes more plentiful on account of the increase in number of the pigmentary granules. This nerve cell while it progresses with the development of life also declines with the decay of life. The evolutionary processes that charactized the changes from immaturity to maturity are reversed, the cell substance is diminished in size, the nucleus becoming smaller, the chromoplasm is diminished, the cell substance contains large vacuoles, the dendronic branches become atrophied and the neura also diminish in size; sometimes the whole cell is absorbed and disappears. This process of shrinkage may go on until the entire nerve cell disappears by absorption. In this way accompanying the diminution in volume we find a corresponding decrease in cell activity and a decrease in the power to influence other cells.

These nerve cells form the nerve path along which certain impulses travel. This implies that in the nerve cell there is a capacity of receiving and transmitting impulses. The impulse when communicated to the nerve cell is manifested in an undultatory molecular variation transmitted along the fibre from the point where the impulse originates. The variation represents an electric impulse moving with a certain velocity depending upon the condition of the nerves, warmth increasing the rapidity and cold diminishing it. It is estimated that in a human subject an impulse travels with a velocity of about 35 mm. per second. Stimulation can be applied at any point along the nerve fibre if the stimulation is sufficiently strong and if the fibre is sufficiently subjected to stimulation. Such stimulation may be applied in the form of heat, electricity, chemical or mechanical stimuli, but all of these are artificial and consequently differ from normal stimulation arising from cell changes, these artificial stimuli producing a stronger variation electrically. When a nerve impulse starts it continues to travel along the same nerve path until it reaches some central point where it is received or distributed, no radiation taking place along the nerve path, these representing the medullated neura from the cells. These nerve paths correspond with the cell neura and the centers with

the cells located in the cerebro-spinal system.

The question arises whether in the case of a single cell with its branches such changes take place and such phenomena are manifested under stimlation. It is true that when the cells are grouped together and the neuronic branches are united to form peripheral nerves such stimulation affects the grouped cells but does not exist in the single cell. The single cell is so small that it is difficult to experiment directly upon it. The principle as found in the combination of cell is usually applied to the single cell elements. In the single nerve cell nervous impulses enter in a certain direction, although thit depends on stimulation, for the nerve cell being stimulated at a certain point the impulse may travel in two directions instead of one. For example, when an impulse enters a cell in connection with the spinal cord at the anterior root there is no passage of the impulse into the other part of the cord, so that while impulses pass from the nerve fibres to the nerve cells in the cord, impluses pass from the nerve cells in the cord, the impulses do not pass in the reverse direction. In the case of the spinal ganglion on the posterior root we find cells that are dineuric, one branch entering the spinal cord and another extending to the periphery. Normally impulses pass from the peripheral end towards the cord passing into the cord to be distributed by the nerve fibres. If the cord is divided just above the point of entrance of the posterior root and stimulation is applied, the variation is noticeable on the peripheral side of the spinal ganglia. In this case stimulation is applied to the spinal end of the ganglion cell, the impulse traveling through the one branch of the cell body entering the cord, then through the cell body in the ganglion and into the opposite neuron. The question is, does an impulse pass or may it pass in two directions. It would seem that in connection with the dineuric cells there may be an impulse in both directions. If the posterior root is stimulated and the spinal cord divided transversely above the point of the root entrance there is not found to be any stimulation passing centrally. The cells originating the anterior roots are connected physiologically by fibres with the other spinal cord cells, but when the anterior root is stimulated no impulse is found to pass from cell to cell centrally. In the case of the posterior root it seems to be different although in reality it is the same. Here the cell body is in the spinal ganglion and the cells are dineuric, one neuron reaching out peripherally and one centrally. Normally impulses pass from the periphery internally. Stimulation of the posterior roots therefore may give rise to impulses in both directions in connection with the cord. If however the sensory column of the cord is stimulated above, the origin of the posterior root at the cross section it is found that a variation takes place on the peripheral side of the spinal ganglion and indicating the passage of an impulse opposite to the normal direction. These stimulations have taken place in connection with the neura of the spinal ganglion cells so that the stimulation has passed entirely through the single cell and its processes.

Thus the impulses may pass in either direction in the case of the dineuric cell. This however would not take place in the intact cord because the stimulus must be applied to the end of the neuron. In the central nervous system it is supposed that impulses pass by a series of such transmissions, the impulse passing from cell to cell, each cell arousing into acivity the neighboring cell. If a cell receives an impulse from one of its neura and then transmits it to another cell through another neuron, these cells must be regarded not simply as paths for the passage

of impulses, but as distributors of impulses; in other words physiologically every cell body is a subsidiary center. In this case the impulse must enter the nerve cell passing along the neura and entering the cell either through the stem or through part of it. In this way there may be a double pathway along which the impulse may travel in reaching the cell. The impulses thus received must pass out of some of the branches and the same condition would exist if the neuron originates from a dendronic base arising from the cell body, the impulses coming along the dendrons and passing out by the neura, in both cases passing along the common part. The question arises whether the branches of the cell are necessary for the reception and transmission of such impulses and therefore for cell functionality. In the case of a fish it has been proved that the cells of the spinal cord can pass impulses without any branches being developed, indicating that the impulse transmission depends upon the cell condition rather than the development of the branches. Thus a modification of the cell wall may take place by which connection for impulses is established between neighboring cells without any branches being formed or before their formation. This modification must take place both for the reception and transmission of impulses. There is no doubt, however, that where cell branches are developed it is a peculiar function of these branches to form such connections. Thus the cell form, particularly the form of the cell wall, and the development of the branches represent important functions in connection with the receiving and giving out of impulses, each dendron representing one path along which impulses may enter the cell. Where the branching is complicated there is a capacity on the part of the cell to give and receive numerous stimuli. In the evolution of the cell this takes place. The primitive cell has no dendrons but first we find the neuron and later the dendrons indicating that this branching process goes on to maturity becoming more complicated till perfection is reached.

When the impulses reach the cell certain chemical changes take place resulting in the sending out of the impulse from the cell, varying according to the changes that have taken place within the cell. This variation is not known except in so far as the strength of the stimulus alters the intensity of the negative variation, the stronger the stimulus the greater the variation. If we add the multiple influences of a vast number of such cells we can form an estimate of the varying intensity of an impulse as it passes along the nerve. After the impulse leaves the cell it depends upon a number of such events taking place along the path. By stimulating the motor region of the cerebrum in the monkey it is found that a single contraction takes place followed by a number of shorter contractions indicating that when the main stimulation has left the central cell there are following rhythmical variations. It is estimated that in the case of the nerve cells in the spinal cord impulses are discharged at the rate of 10 per second, estimated from the rate of the production of tetanus. The spinal and cortical cells discharge impulses at the same rate. It has been supposed that a nerve cell may be stimulated at any point although there is no evidence to bear this out. As the cell lie embedded in the ends of other cell branches it is impossible to say whether the impulse passes directly from cell to cell or through the neura. It is probable that every part of the nerve cell is subject to stimulation and hence possesses irritabilitp. It cannot be proved that by stimulating directly the cells discharge takes place.

Wherever the cells are found they seem to be embedded in neuronic terminals originating from other cells; hence all the different parts may be said to be excitable. Side by side with irritability as a nervous property is conductivity although there are parts of the nerve fibre in which conductivity is present while irritability is absent. If the phrenic nerve is laid open and compressed by the fingers the diaphragm contracts. After the exhaustion of this part, if near to the cord the nerve is again compressed by the fingers the diaphragm contracts. After the exhaustion of this part, if the nerve is still compressed diaphragm contraction will still result. Thus after the irritability has ceased conductivity still continues active. The same thing is true in the case of degenerated portions of the nerve when passing through regeneration. Although they will not respond to direct stimulation they will carry stimulation from an irritable part that is normally developed and matured. This indicates the possible presence of conductivity all along the nerve paths both in the cell bodies and their branches. What amount of stimulation is necessary to secure a discharge in the case of a single cell is not sufficiently understood. although in the case of a single cell a single stimulus produces a single impulse. It is probable, however, that to sustain the transmission of impulse a sumnation of stimulations is necessary, the discharge taking place in connection with this steady stimulation. The necessity for this continued stimulation may arise from the fact that certain chemical changes take place in connection with the reception and discharge of the impulse by the cell, possibly the time is occupied in the passage from one cell to another. These chemical processes represent the metabolism of the nerve cell which is continuous. During the cell katabolism certain substances are formed by breaking down the cell substance which reseults in the discharge of the energy of impulse, producing such a change in the walls of the cell that it is possible for osmosis to take place in connection with cell nutrition. In this way the transmission of impulses including the changes that take place in connection with the cells has an important bearing on the nutrition of the cell. The changes are most active in connection with the cell when the blood capillaries surround the cells. In regard to the chemical changes that take place in the cell little is known except that during cell activity the nerve substance becomes less alkaline at times becoming slightly acid. The passage of nerve impulses is necessary to the preservation of the trophic condition of the cells for if the cells cease to be active they degenerate. This arises from the fact that by the passage of these impulses certain changes take place that have a trophic influence upon the nerve tissue and the arrest of these changes leads to an atrophied condition.

This is evident in the case of the amputation of limbs those nerves becoming atrophied that cease to possess functional activity after the removal of the limb. The neuronic portions arising from the cells located in the anterior horns of the spinal cord or when the cells of the spinal cord itself are removed. In the latter case the impulse is prevented from entering because of the interruption of the peripheral function; and in the former case the impulse is prevented from being delivered from the cell by the destruction of the peripheral portion. In the case of the spinal ganglion cell the nerve path by which impulses pass into the ganglia is partially destroyed although some impulses do pass as is manifest from the sensations that are felt even in the case of the amputation of the limb. The spinal cells are thus cut off from one of the pathways of the impulse

namely those that reach the cord through the posterior roots. although other pathways of stimulation remain. Similarly the efferent nerve path is cut off and certain Impulses pass outward to the ends of the amputated limb. These impulses tend to contract the muscles surrounding the stump indicating that the efferent impulses mark the discharge from the cells. Hence the fibres although losing their connection in the amputated limb still retain their activity. If the afferent impulses are cut off from the cell or group of cells, then the cells become more or less atrophied by the destruction of these fibres, indicating that the activity of the cells possesses nutritive value and that the different cells physiologically aid in the nutrition of each other.

The cells vary much in their power of using the nutriment surrounding them. Tissues are liable to become exhausted. By the use of the induced current in stimulating afferent fibres it is found that changes take place in the cells. By experiments in connection with the spinal cord of a cat it has been found that the artificial stimulation of the cells by electric irritation produces changes in the cell bodies. The prolonged stimulation applied for fiive hours, the stimulation being applied for 15 seconds in every 60, resulted in a shrinkage of the cells and the flattening of the sheath nuclei, the shrinkage depending upon the time during which stimulation was applied, being greater the longer the time during which stimulation takes place, so that the change depends on the stimulation and the length of application. It has been demonstrated that this change in the cells is physiological as the cat recovered by a period of rest after such changes were produced. The question arises does this change take place in the living condition. By the use of the nervous tissue of the cells of the sympathetic ganglia of frogs it has been demonstrated that these changes take place in the nerve cells in the living subject, the resting condition representing the large spherical form of the cells and the shrunken condition representing the change upon the cells by activity. The frogs were kept alive by means of a nutritive process according to which the cells were nourished. Still further experiments were made on animals killed at the end of a resting period and at the end of an active period, indicating the existence of the changes already found. These changes then take place normally in the human subject, the changes varying according to the degree of stimulation and the amount of nutrient plasma surrounding the cells. Thus there are certain definite changes taking place in the cell bodies in connection with nervous activity, the larger cells becoming contracted and the rounded nuclei becoming flattened, these changes representing the normal passage of impulses through the cells. In connection with the cells there may be abnormal conditions represented by the nutrition as in cases where poisoning takes place either by the use of a poisonous substance or in connection with the toxic substances arising from diseased conditions, the cells being affected materially. In the case of the nerve branches from the cell no such changes have as yet been found to take place.

The entire cell body is subject to the control of the nucleated part, the nucleated part being therefore the most important. If a nerve fibre is cut off from the cell body from which it has developed the fibre will soon degenerate, the degeneration taking place at the same time along the entire fibre. This degeneration consists of degeneration or disintegration of the axis cylinder which graduallly disappears, the medullated part being absorbed leaving the primitive sheath and the nuclei of the

sheath. During the degeneration the medullary sheath changes chemically but the change is not understood. In the non-medullated fibres degeneration takes place rapidly the changes taking place in the central part of the external portion and the nuclei remaining intact. In the central nervous system the peripheral parts of the fibres which are divided from the cell body degenerate. Thus the nervous system is under the control and dependent for nutrition upon the cell body. Section of the posterior root at the peripheral side of the spinal ganglion in the case of the spinal nerves results in degeneration along the fibres to the peripheral side of the ganglion. Section of the posterior root on the spinal side of the spinal ganglion causes degeneration of the nerve fibre to the spinal side of the cell body. Section of the anterior root causes degeneration to the peripheral side. In both cases the degeneration takes place on the side away from the cell body. When section of the nerve takes place there is always central degeneration to the next Ranvier node as well as peripheral degeneration. Degeneration on the central side beyond this node depends on circumstances. If the regeneration is prevented certain changes take place, namely, the cessation of development and the atrophy of the affected part. In the case of the removal of a limb these changes are noticeable in connection with the cells of the spinal cord. In the case of young animals when nerves are removed from their connection with the spinal system they are severed just at the junction with the spinal system. In this way when afferent nerves are removed atrophy takes place in the cell body in connection with the spine and any of the cell branches within the spine. these disappearing entirely. The reason of this is that in growing animals the struggle for existence is so strong that these weakened cells cannot compete with complete cells, that is, the complete cells with their attachments. This has an important bearing on the human subject as certain injuries during the fœtal life affect these bodies preventing development. resulting in the abnormal condition of certain parts of the spinal system. It has not been proved that such a disappearance of cells does takes within the central system or the spinal ganglia as in most cases it has only resulted in atrophy of the cell.

If the severed ends of a divided nerve are brought together the fibres may be completely regenerated. While the dissolution and absorption of the medullary sheath is taking place, the nuclei and the protoplasm in proximity with the nuclei enlarge forming new substance inside the old sheath. Later there is formed a new sheath over the new substance forming a new embryonic fibre on each side of the division. union taking place in this new substance. Around the nuclei of the sheath new parts are formed constituting a new tubular sheath the new axis cylinder following the formation of this tubular part and slightly later in development. The formation of the axis cylinder takes place last in the regeneration process although it is the most important part. The growth of the axis cylinder takes place from the central end representing the process of formation out from the cell body just as in the embryonic formation of the neuron from the cell. The regenerated fibre at first is small in size, growth taking place gradually in assuming the normal size. Conductivity appears first in the new fibre just as it was the last to disappear. irritability appearing later, indicating that regeneration takes place in distinct stages the restored function marking those regeneration changes. Even in the restoration of irritability to the new fibres there is a response to electrical stimulation. It is not known that the regeneration

process takes place in the central nervous system. In the case of degeneration of the posterior roots between the cord and the ganglion the regeneration takes place from the central end by the growth of the central part, the growth in this part being slow, the sensibility returns before mobility indicating also a difference in the restoration of function. In the case of regeneration of nerves the fibres appear to follow the old nerves under the guidance of the old sheath. But in the case of a nerve there are both afferent and efferent fibres and the question is, does the exact regeneration take place in those afferent and efferent fibres on the old basis. Attempts have been made to connect the cut ends of distinct nerves, for example, the median and ulnar nerves of a dog, the result being a regeneration of the distinct nerves without any lack of coordination and with distinct movement and sensation. It is impossible to explain this as the different functions of the fibres do not seem to have interfered with sensation and motion although the nerve paths were united crosswise. Langley cut the pre-ganglionic nerve fibres going to the superior cervical ganglion in the cat, these fibres springing from the first to the seventh thoracic nerves. By allowing regeneration to take place he found that each fibre united with its own characteristic cell process indicating that in the regeneration process the fibres had the power of selecting its cell origin and that in the selection it made the original selecton. The question arises can there be the formation of an entirely new cell or cell elements in the process of regeneration. There seems to be no evidence of the formation of new cells in connection with the central nervous system, at least in the human subject. Experiments are cited in which in some lower animals new cells have developed although these seem to have developed from embryonic cells. In the case of injuries to the central nervous system there is no evidence of any cell division or nuclei division. It has been reported that such a cell division takes place in some of the lower animals in connection with the spinal cord but even in these cases it is probably due to the enlargement of already existing embryonic cells. Changes that do arise therefore depend upon the enlargement of embryonic cells which mark the early stages of growth in the nervous system. A cell if injured or atrophied can not be replaced by an absolutely new cell in the case of the central nervous system.

SECTION IV. The Physiology of Cell Combination.

The nervous system consists of certain pathways from the external to the internal representing the movement of impulses, these pathways being certain localized centers of activity. The nervous system while consisting of certain paths and centers forms a unit. For arrangement it is usually divided into a central system and a peripheral system but neither of these divisions is natural nor independent, being considered simply in their separation for the purposes of arrangement. In the nervous system we find three groups of nerve elements: (1) Central cells with their neura which lie inside the central system whose function is to receive and distribute the impulses along the nerve paths. (2) Afferent nerve cells along which impulses pass from peripheral portions to the central nervous system. (3) Efferent nerve cells representing the cell branches that pass from the cell bodies inside the central system to the different parts of the body outside the central system. In this is included those efferent elements whose cells lie in the central system and

those outside the central system found in the sympathetic ganglia and the scattered plexuses. The posterior roots in connection with the spinal and cranial nerves represent the only pathway into the central system. After reaching the nerve the impulses enter cells passing from cell to cell in their way internally in the central system. Thus the afferent impulse passes from cell to cell until it reaches the cell which discharges it along an efferent path passing out from the central system, the anterior roots passing either to the muscles or the sympathetic ganglia; the fibres passing through the latter and terminating in plexuses or at least in the tissues. The spinal cord consists of nerve centers and nerve fibres and represents a collection of reflex centers and a transmitter of nervous impulses. The spinal cord conveys impressions in two directions by the afferent paths which enter the cord by the posterior roots of the spinal nerve. The impulses almost immediately pass over to the opposite side of the cord and pass upward. Hence section of one half of the cord produces loss of sensation on the other side of the body in the area supplied below the line of section. Impulses travel downward in the antero-lateral column and then pass outwards along the anterior roots of the nerves on the same side. Hence section of one half of the cord produces muscular paralysis on the same side of the body over the area supplied below the line of section. In this latter case there are two classes of efferent cells, (1) those whose cell bodies lie inside the central spinal system, the branches representing the anterior spinal roots, and (2) those whose cell bodies lie in the peripheral ganglia outside the central nervous system.

The central nervous system represents the large mass by bulk of the nervous system and also a much greater number of cell bodies than the afferent and efferent elements. Thus the cell elements in the central system are the most important representing the function of distribution and reception; it is in these that the increase in complexity is found associated with the development of the nervous mechanism. In the early embryonic stages the cells have no connection being at first isolated from each other and later forming branches which have not as yet developed their connections. In development towards complete neural organization this connection becomes fully established by means of the neuronic and minnte cell branches, especially in the development of the dendronic and the neuronic branches and in establishing their relations to each other. In the cells of the cortex, for example, the branches gradually increase in number representing the evolution from the lower to the higher vertebrates. These increasing branches increase the size of the cortex substance having an important functional bearing upon nutrition and also increasing the capacity of receiving impulses, the dendronic branches representing the receiving parts of the cells. As these dendrons increase the variety of internal impulses is increased. In the afferent, central and efferent cells we find two neura, the impulses entering at one neuron and passing out through the central neuron that has a great number of branches in the central system cells. In the case of the central cells we find great variation in the number of branches, being very numerous in the pyramidal cells of the cortex and very few in number in the posterior horns of the gray matter. Each cell is independent in formation, the outgrowth from the cell representing the neura and the other branches. In the human subject cell communication seems to be established in the case of the central system by means of cell contact and not by the union of the cell branches of the different cells. The cells are brought together in

different ways. In the case of the cells of Purkinje in the cerebellar cortex the [illegible] are found to terminate in the basket shaped frame of the neura of the pyramidal cells, in this case the connection taking place between the cell body and the neuron terminals. In this case the dendrons do not represent the only path along which impulses pass that affect cells.

The nervous system consists of cell elements that approximate together although they are not continuous. How then does the impulse pass from one cell element to another? The passage of impulses will depend on chemical changes taking place in the connecting points of the branches, these changes taking place slowly. Thus the stimulation passing to the terminals stimulates the substance that intervenes between the one and the other of the branches. When an impulse is brought to the spinal cord through the posterior roots it is received in the cells in which the neura terminate. Hence the first element is the determination of the way in which the posterior roots end in the cord and are distributed. When the afferent neuron enters the cord it divides into two branches, the short one passing towards the periphery and the large one towards the brain passing over the whole length of the cord or the greater part of it. These branches are connected with the spinal cells by means of subordinate branches. These central cells form series through which impulses are transmitted so that the effect may be produced on the efferent cells directly or the stimulus may pass along the cord to a distant part. Along the length of the cord there are 31 afferent roots on each side, there being an efferent root anteriorly corresponding with each posterior root. In this way the whole length of the cord is divided into homologous segments, the segmentary arrangement following the pairs of spinal nerves. The efferent cells are located at the same level as the efferent fibres originating from them. In the case of the afferent fibres they enter into the cord and are not limited to any definite segment area as are the efferent roots, these springing immediately from the cell bodies in the segment of origin. Yet we find that each segment contains a number of central cells which are connected with the afferent and efferent roots. This segment division of cells is not so complete in the human subject as in some of the lower vertebrates. In this way we have a bilateral symmetry more or less perfect in the arrangement of the cord and the afferent and efferent fibres. The symmetry is not perfect as cell is not exactly balanced by cell on the two sides of the cord, although in the same region the number of cells is the same. Throughout the entire central system we find neuronic branches passing from one side to the other as in the intersection of the pyramidal fibres and in the posterior commissure of the spinal cord. This may be effected in the cells of the central system either by the neuronic or the subsidiary branches of the cell bodies. These commissural fibres represent only a small part of the central system. The neura of the posterior root enter the posterior column of the cord and do not cross while the neura of the efferent cells cross in connection with the anterior commissure, although it is mostly the neura of the central cell that cross. The crossing takes place in connection with the central cells either through the neura or their branches.

In the embryonic condition the spinal canal represents a tube with indented sides, each side of the tube being divided into an anterior and posterior part. These form the primitive plates in which are localized cells

which later have different functions. The neura coming in from the spinal ganglia center in the posterior plate, the cells in the anterior plate giving rise to the other neura. In both plates are found central cells particularly at the junction of the plates. The branches of the afferent cells are found in both plates so that in this way the central cell lies between the efferent cell and the neuron of the afferent cell. As we pass to the brain and the basal ganglia we find that the central cells only are found, which correspond with the central cells found in the spinal cord. Impulses are supposed primarily to originate at the periphery, although the spinal cord is not merely engaged in the transmission of impulses, the nerve centers it contains being capable of originating nervous impulses under the influence of afferent stimuli. Thus it is necessary to have an external stimulus in connection with an end plate organ. During normal life stimulation is constantly taking place so that the nervous system is constantly subject to the stimuli that produce changes varying with the variations in the stimuli and also with the chemical changes in the cell bodies. If the stimulus imparted to the nerve in the form of an impulse travels through a single nerve fibre the impulse will vary directly with the stimulus in strength. If one cell impulse arouses another cell impulse there is a variation in the impulse due to the changes taking place in connection with the transmission of the impulse If the impulse only passes through a single neural element the response is directly proportional to the stimulus; but when the impulse passes from one cell to another there is greater variation depending on the effect of the stimulation passed from one element to the other. As it enters the central system there is found to be complexity of the elements. In this way the impulse is passed along the central system with a diminished intensity this diminution taking place in connection with the minute branching of the cell branches. Thus impulses passing into the central nervous system are distributed and also they become weakened, until terminating in an afferent cell, the impulse is discharged along an efferent path. The impulse in its passage thus reaches a large number of cells and it is discharged from these cells in its transmission from one to the other; and all the cells it enters do not necessarily discharge an impulse, so that this does not represent the only pathway along which it may pass in its passage through the central system. The nervous system is thus kept in a constant state of stimulation, so that impulses reaching the central system affect it with varying degrees of intensity, their variation depending upon the fibres and their cell connections and also upon the physiological and chemical condition of the cells.

In the case of contraction of the extensor muscles of the knee by a blow upon the tendons below the knee there is an extension of the leg, a jerk taking place from the knee joint. It is found that the variation in this jerk corresponds with the changes in the spinal cord at the point from which the nerves emanate. Great variation is found in different persons at different periods. The greatest variation is found in the passage from wakefulness to sleep and vice versa. The value of this is found in the fact that it may be used as a means of testing the spinal cord. If the lumbar portion of the cord is injured or its connection with the upper centers is cut off there is found to be no response. Possibly other reactions may be obtained of a similar nature at different parts of the system, but these indicate that every stimulation brought to bear on the spinal cord have an effect upon it so that if we take account of the very numerous

normal stimulations which are constantly passing into it and affecting the responsiveness, we can see the influence that is exerted upon the system as a whole. The extent of this modification resulting from impulses brought to the central system depends on the condition of the fibres and also on the condition of the central cells when the impulse reaches those central cells. Hence where the afferent nerves have the greatest central connection we find that the influence is greatest as for example in connection with the first, second and eighth nerves.

In regard to the condition of the central cells it is found that great alterations in the effect produced by incoming impulses depends upon the use of certain substances, particularly drugs. Thus the physiological and chemical condition of the cells may be materially influenced by the use of drugs. The frog poisoned by strychnine is found to be very easily tetanized, the strychnine accumulating in the spinal cord substance, the result being that very slight stimulation produces a tetanic contraction of the muscles and gives a very ready response. It is supposed that strychnine acts upon the bodies of the central cells and also upon the terminal points of the central impulses in the cord or afferent cells. In the central system the diffusion of impulses depends also on the association of cells so as to secure the wide diffusion of impulses. The diffusion of the efferent impulses depends upon the cell arrangement. When the impulses are sent out from the cells they pass out of the cord by the anterior roots although they may pass from the lateral and posterior roots where these are found reflected in connection with the cord. The impulses thus sent out from the cells along the neuronic branches (1) may be distributed to the voluntary muscle fibres. In this case there is simply a distribution of the impulses to the region controlled by the fibres. No diffusion takes place in the motor fibres themselves there being simply a distribution in connection with the efferent nerves. (2) These impulses may also pass to the sympathetic ganglia. The sympathetic system including the ganglia and plexuses are connected with the efferent branches from the central nervous system. In the sympathetic system we find mononeuric nerve cell bodies, with or without dendronic branches. After leaving the spinal cord by the efferent neura we find the ganglia in which there is a group of nerve cells, the neura for these cell bodies passing out towards the nerve plexuses. In the ganglia we find a number of cell bodies, larger in number than the neura from the spinal cord thus increasing the nerve paths towards the peripheral pleuxses. Thus we have certain fibres originating in the spinal cells called pre-ganglionic and others originating in the spinal ganglia passing out to the periphery called post-ganglionic. The former fibres are intercepted in the ganglia and are medullated, originating from the thoracic to the 5th lumbar. According to Langley no sympathetic cell gives out branches to another sympathetic cell. The fibres originating in the ganglia are mostly non-medullated although some are medullated at least periodically along the fibre path. The cells in the ganglion are not connected together although various fibres enter into the cells from the spinal cord cells. The neura from the cerebro-spinal cells end in the ganglia so that pre-ganglionic branches end in a number of ganglion cells, these cells sending neura to the periphery. When the neuronic branches pass from the ganglia towards the peripheral plexuses they form a great number of branches representing the diffusion of the impulses either in plexus form in connection with the internal organs and blood vessels or as sympathetic fibres to the periphery. The pre-gan-

glionic fibres are connected with a number of ganglia cells so that as the impulses leave the ganglia they are increased. At the same time the grouped cells of the ganglion are not connected together.

Normally the striated and unstriated muscle tissues are in condition of tonic contraction. If the nerves supplying the muscle tissues are cut the tonic contraction gives place to relaxation. If the cord is extirpated the efferent impulses that keep the muscle in a state of tonic contraction are destroyed, the muscles becoming relaxed. If in a frog the brain is removed the muscles are still found to be contracted. If the sciatic nerve on one side is then cut the leg on that side becomes relaxed. This seems to indicate that impulses are constantly passing to the muscles from the central system that preserve muscle tonicity. The difference in the degree of the impulses sent from the cord represents the difference in the condition of the muscles, found, for example in those who exercise the muscles as compared with those who take no exercise. In the case of insanity the tonic contraction of the muscles is to a large extent lost, at least in some cases, depending upon the loss of nutritive elements in connection with the central nervous system. It is this that gives the maniac those characteristic facial and muscular expresions that represent want of activity and are called expressionless. In some cases of violent insanity the changes from the one condition to the other represent marked changes in the nervous impulses transmitted from the central system to the muscles. The same flow of impulses from the central system is associated with gland activity, representing the neural basis of metabolic changes. Even in the final struggle of life represented by death we find the nerve tissue undergoing a chemical change, originating impulses which after passing to the motor fibres produce the characteristic rigor-mortis or cadaveric condition. If an animal is suddenly killed and if one sciatic nerve is at once cut the rigor mortis will begin very much sooner in the leg in which the sciatic is intact, indicating that the nerve connections with impulses passing along these nerve connections modify the after death conditions. When the normal nervous impulses are allowed to pass after the body death the changes producing rigor mortis are more characteristic. Thus we find afferent or sensory nerves representing varying impulses passing into the central nervous system from the sensory system, the impulses passing into the cerebro-spinal system at the point of connection with the cerebro-spinal system. The impulse passes from the afferent to the central cells several pathways being opened in connection with these central cells all of these being usually traversed by the impulses. These impulses arouse a response which takes place through efferent cells, the response representing impulses emanating from the central nervous system to be diffused among the ganglia, plexuses and finally passing to the muscles and secretory tissues. The afferent impulses are limited to the single pathways represented by the single cells, whereas the efferent impulses in passing through the sympathetic system have an enlarged pathway representing larger diffusion, at least two elements being opened up in connection with the sympathetic system.

The great question that arises then is in regard to the passage from afferent to efferent cells in connection with the central cells of the central nervous system; and how this transference takes place in connection with the central cells. Here the main problem is that of distinction between a voluntary and a reflex action. Reflex action in the case of the transfer from afferent to efferent involves the absence of consciousness.

the action being dependent entirely upon physiological conditions and relations. If the spinal cord is cut just below the medulla so as to cut off all the upper portion of the central system the animal will be in a collapsed condition. On dissecton of the animal the afferent fibres from the cutaneous surface, the spinal cord and the spinal nerves passing out by the posterior roots will be found intact. Hence we have the mechanism of reflex action, namely an afferent path, nerve cells in the cord forming the receiving and distributing center and an efferent path for the outpassage of impulses. If the cutaneous nerves are irritated muscle contraction will follow, the contraction following the segmentary arrangement of the cord according to which they are supplied with nervous branches. The muscle contraction depends on the strength of the stimulation as well as the length of the continuation of the stimulation and the number of muscles that are supplied with nerve connections from the same cell area. Normally the contraction represents not spasmodic action but coordinated movements. The response in the contraction of the muscles may continue after the removal of the stimulation, if there is sufficient chemical change in the cell or cells along the path of impulse, the chief changes taking place in the central cells. After the stimulus is applied there is a latent period during which no response is given, after the latent period the response being given in the muscle contraction. If the stimuli are increased so that there are a number of single stimuli the response is the result of the summation of these stimuli, the impulses being collected at some point until there is sufficient force to discharge the impulses along the efferent nerve. This summation takes place either in the nerve cells themselves or else in connection with the afferent fibres along with these nerve cells. The various segments of the cord have independent functional activity in the control of certain regions, the connection of these segments representing the coordination of impulses as to time and degree of stimulaton. It is believed that the cord of a frog may be divided into three such segmentary portions giving characteristic reactions. These impulses are constantly passing out through the muscles and secreting glands, the impulses depending on the strength and the character of the afferent impulses. The impulses that pass to the cord upon stimulation of the afferent paths pass through varying changes before being distributed and transmitted outwards, indicating that the cells receive and then arrange for the distribution of these impulses. This may be due to the fact that impulses are not distributed in the same way in the different cells or it may be due to the difference in the matter of responsiveness in the central and efferent cells. It must be remembered that the condition of the cells and the body is postmortem so that changes may take place in connection with the cells and also the stimuli, so that the muscles may not give their normal stimulation to the central system.

In connection with the muscle responses of a brainless frog the responses are found to be purposive the response tending to remove away from the irritation. By placing an acid on the one side of a frog the limb is raised to try and remove it. Some physiologists have spoken of selective affinity in connection with the central cell, alleging that these cells are capable of choice in the distribution of the impulses. This so called psychic element however in the central cells seems to follow physiological rather than psychological conditions. The difference as we have said in the reaction is due to the extent of the stimulation, its intensity and also

in a large measure to the condition of the central nervous system. It is claimed that when one foot is held fast and acid is applied to the body the foot held fast on the same side as the irritant first tries to remove it and failing the other foot makes the attempt. The readjustment however is not absolutely accurate. It is better to explain this on the basis of the diffusion of impulses in connection with the spinal cord without any psychic action. Besides there is much difference in the intensity of the response to the stimulation in different conditions. In some animals like the fishes the spinal cord is much simpler the locomotive actions being almost constant, for example, the duck can swim and even fly with coordination of movement when its head is cut off. In the case of the dog if the lumbar region is divided from the rest of the cord the animal can live and will continue to respond to stimulation. In the human subject the separation of part of the cord from the rest of the central nervous system results in rapid death, particularly if the division is sudden. There are however cases in which pathological conditions have practically cut off the spinal cord from the nervous system in connection with which reflexes have been noticed. Hitzig points out a case in which an entire division between the last cervical and the first dorsal did not prove fatal, the patient living seven years. The chief reactions in these cases are found in connection with the muscle contraction of the limbs under stimulation the locomotive reflexes being lost. In the human subject reflex reactions are found chiefly in connection with the secreting glands and the unstriated muscle tissues of deglutition, defæcation, and in connection with peristaltic movements. The whole vascular system is regulated reflexly. Thus reflexes are chiefly in connection with the unstriped muscles. It is to be noticed that reflex action may come to be under the control of the will, changes taking place probably in connection with the development of the neuronic branches from the cephalic cells into the spinal cord, the cord cells being subject to new impulses coming from the higher centers. In this way micturition and defæcation as well as respiration and even the heart pulsation can be controlled by the will. The same thing is true of certain reflex actions that disappear with the development from immaturity, for example, the case of sucking in a child. Impulses tend to diffuse over the central system when they enter the cord. In the brainless frog these impulses are not allowed to diffuse to their utmost. The tendency in the complete system is to send the impulse through the entire nervous system whereas in the divided system the impulses after passing to the point of division are lost because there is no power to return. Hence in the brainless frog the part absent yields no impulses and the pathways are lessened for the afferent impulses by the division of the neuronic branches of the afferent cells. A definite amount of activity in the case of the cell is necessary to sustain its normal condition, this activity being the basis of the cell nutrition. If the activity is diminished then the power of response is also diminished. It is said that to dip a frog in a cocaine solution deprives the central system of the power to respond to stimulus to such an extent that even sensory impressions call forth no response. Thus the activity of the cell substance is the basis of its capacity for receiving and distributing impulses.

A voluntary action as distinguished from a reflex one implies the freedom of the will to change the response, not only in the form which is assumed by the response but also in the time at which the response is given so that delay in giving the response may extend to years, the stimu-

lus providing the stimulation that after a long time results in activity. The stored up stimulation may be recalled by an association that brings it to the front. Here consciousness or the psychological element enters in to vary the physiological development. In order to carry out the complex voluntary actions the whole nervous system is called into action, especially the upper part of the brain in which are localized the higher centers. Reflex actions may take place with afferent and efferent fibres and the small segment of the spinal cord; whereas voluntary actions involve a wider path taking in the afferent system together with the spinal cord and the cephalic cells and also the efferent system under the control of a large number of cells. In the human subject the posterior root fibres enter the cord in three groups, the median, intermediate and lateral groups of fibres, the last group being very delicate. If the posterior root is divided on the spinal side of the spinal ganglion all these fibres degenerate. This degeneration is found to reach down along the posterior column a short distance and up the posterior column as far as the lower part of the medullary region where the dorsel nuclei are located. In case of section towards the peripheral end of the cord the degenerated fibres may be found running all through the cord but only on the side of the cord in which the fibres run. This means that all along the spinal cord we find posterior fibres running the length of the cord at the same time as we find collateral branches which are distributed at different points along the posterior column, these fibres being continuous with those found in connection with the horns. Very few of the posterior root fibres run along the entire posterior column of the cord, those fibres in the cord being continuous with the posterior roots, and, therefore, representing part of the afferent system. The intermediate and lateral groups of fibres also pass into the gray matter of the cornua where they form connections with central and efferent as well as afferent cells. The pathway for the continuation of the posterior fibres therefore must be found in connection with the neura of the central cells. If the spinal cord is divided in one lateral half the fibres degenerate on the side of the section, although fibres also degenerate on the other side, these fibres representing the afferent nerve paths. Those impulses entering the cord from the posterior roots may pass along the nerve fibres representing the continuation of these efferent fibres, or they may pass through the central cells and in some cases to the opposite side. The lateral columns of the spinal cord represent the afferent paths for impulses involving motion and sensation on the peripheral side of the section. Hence the fibres that degenerate after the hemi-section represent the neura from the central cells. These cells are found along the entire cord close to where the posterior roots end. In the medullary region we find such central cells in connection with the sensory fibre nuclei, the same kind of nuclear cells being found in the cord with homologous nerve fibres. When the degeneration takes place in the central system it results in the total destruction of the nerve fibre, the medullary sheaths being modified and in some cases a series of nerve cells being affected.

The stimulation of the sensory fibres of the sciatic nerve is found to raise the blood pressure. By dividing the lateral columns of the cord the stimulation of the sciatic produced a very slight rise in the blood pressure, the effect being greater if the lateral column on the opposite side is divided. This indicates that the lateral column represents an important path for afferent impulses. According to Gotch by stimulating a post-

erior root .8 of the impulses pass along the same side of the cord to the brain, the remainder passing to the opposide side, the majority of the impulses pasing up along the posterior column. This would indicate the posterior column as the chief afferent path. By dividing all the parts of the cord except the two laterial columns it was found that sensibility and motion of the hind legs were not interfered with, while the division of all the cord except th e anterior and posterior columns resulted in almost the total loss of sensation with only partial disturbance of voluntary movements. By dividing all the cord except the posterior column sensation and motion were entirly destroyed. The lateral columns therefore of the cord represent the chief path of sensations and motions peripheral to the point of division; to preserve the posterior column does not preserve sensation. The question arises whether the posterior fibres from the cord represent all the sensations of heat, cold, pain, pressure. etc. It has been estimated by Stilling that there are 500,000 posterior root fibres indicating the adequate nerve supply from the muscles and cutaneous tissues. It is claimed that one nerve fibre supplies innervation to about six square millimeters of skin surface. The skin is not evenly supplied with nerves as it is stated that the skin of the arm is much more plentifully supplied with sensory nerves than the leg, the supply being more plentiful in both at the extremities, particularly in the leg. The afferent fibres that collect and carry the cutaneous impressions are developments of the spinal ganglion cells. The sensations of heat, cold, compression including pain are said to be represented by special nerves. It is supposed that in all these sensations if the sensations are extreme there is pain, that is, when the stimulation is normal the ordinary sensations of cold, heatand pressure result while excessive stimulation results in pain, the sensation of pain including the other normal sensations. Thus pain depends not on the existence of special sensory nerves but rather on the intensity of the stimulus, or the extent of the nerve surface that is included in the stimutation.

This means that a physiological analysis of pain makes it an excessive excitation, including the conveyance of abnormal impulses to the central system and an abnormal discharge of those impulses from the central system; these excessive impulses destroy the coordinated reactions of the muscles producing intermittent actions such as we find associated with painful sensations. Hence excessive stimulation in connection with the skin or muscles produces the painful sensation. great differences being found in different persons. In some there is the absence of the sensations of pain while others are very sensitive to their production. From the standpoint of the production of pain and the amount of pain it depends largely on subjective conditions and circumstances associated with the individual in particular cases. If the peripheral surface of the body is in a condition of irritation, as for example, in inflammation the pain sensations are intensified; the same thing is true if the sensory stimulation takes place for a lengthened period; on the other hand the use of cocaine reduces the sensibility to a minimum and even suspends it temporarily. There may be such a stimulation in excess as would produce the painful sensation without any real effect being produced, the person being in this case insensible to pain or this analgesic condition may be developed in connection with one of the sensations of pressure. cold or heat when there are certain lesions in the central system which may produce this cond-

tion. Hence pain depends on the excessive degree of stimulation associated with these normal sensations, the nerves when thus excessively stimulated losing their normal sensitive function and becoming abnormal. Hence to increase the stimulation in connection with the increase of the number of sensitive fibres affected will produce the sensation of pain. When this stimulation passes from the peripheral nerves to the central system the result is that spasmodic reactions take place somewhere in the central system. We are unable to locate the point or points where these reactions take place because it is only in consciousness that these painful sensations are felt. It is claimed by some that there are distinct nerve fibres of pressure, heat and cold so that even if they have the same cell connection their function is different. It is claimed that it is found in connection with the special senses that whatever its stimulation may be the same sensation results indicating the specific character of the neural energy. Hence the manner or kind of the stimulation does not alter the response but the response is determined by the cells in the central system. Whether this is so or not cannot be determined; possibly the character of the impulses is determined by the nature of the peripheral stimulation, at least to some extent, so that different fibres are capable of different stimulations, the cell connection determining the sensation resulting. It is said that the different branches of the cutaneous nerves are susceptible of different sensations, accounting for the difference in the case of the application of different stimuli, different sensations resulting from these impulses passed to the centers. Some physiologists claim that the difference in the sensation depends not on the nature of the stimulus but on the character of the cells in the central system. It is more probable however that a difference of stimulus affecting different nerve fibres leads to different nerve impulses being carried to the central cells.

The question of the distribution of impulses among the afferent paths and as to the passage of the impulses associated with heat, cold and pressure is here raised; some of these sensations may be absent or lessened and it would be easy to settle this question if we could say that such a condition is associated with interruptions in the nerve paths. In the human subject it would seem that if there is an injury to the one lateral portion of the spinal cord it is accompanied either by the loss or the diminution to a greater or lesser extent of the sensations, greater on the opposite side to the lesion and also a loss or interference with motion on the same side. Man seems to differ from the lower animals as in these the half section of the cord seems only to have a temporary effect. In one case we find that where the one lateral half was injured and also the gray matter of the anterior and posterior horns the tactile sensation was not interfered with although the pain sensation was lost on the opposite side of the body. It has been inferred from this that the sensation of pain after entering the cord crosses to the opposite side and passes to the brain along the posterior column. It has been found in experiments on monkeys that the sensory impulses after entering the cord at once cross to the opposite side while the tactile sensations seem to pass on the same side as that of the hemi-section of the cord. The visceral sensory impulses possibly pass along the cord to the brain in the cerebellar tract mainly, although other pathways may be followed. Thus the posterior and lateral columns seem to represent the afferent path for the impulses from the sensory nerves. These posterior pathways of the cord are associated with the nuclei of Goll and Burdach on the same side. The neura from

these cells pass towards the brain intersecting each other in passing across the cord, passing to the cortex cerebri either directly or through the thalamus, indicating that the impulses have crossed in their connection with the cerebellum and the cerebrum. The posterior column fibres are united with those arising on the opposite side and with the opposite hemisphere. The neura from the nuclei of Goll and Burdach partly pass to the cerebellum through the inferior crus cerebelli, the cerebellum and cerebrum being connected crosswise, especially with the motor area of the cerebrum. According to this the sensory impulses pass up along the antero-lateral column and after crossing recross to enter the cerebral hemisphere on the same side as that of the sensory stimulation.

As the impulses pass up we meet with the sensory cranial nerves. Among the sensory cranial nerves those that deviate more particularly from the spinal type are the first, second and eighth. In connection with the olfactory nerve it is found by tracing its course that the parts associated with olfaction in the brain are closely associated with the cerebral hemispheres particularly because the earliest cerebral development took place in connection with olfaction. This early nuclear localization however has not been continued because in man we do not find the olfactory tracts and areas so fully developed as other areas and tracts. The impulses of smell pass from the nasal origin by the olfactory tract through the olfactory bulb on the same side, passing thence to the olfactory terminal, one section of the tract going directly to the fornicate convolution and the other to the temporal portion of the hippocampal convolution. The second nerve represents the cerebral tract connecting the retina with the cerebrum. At the optic commissural chiasm where the fibres from the two optic nerves are intermingled they pass out as the regular optic tract to which are added the fibres from the related portions of the brain. In connection with this chiasm the most of the fibres of the single optic nerves are found to pass into the tract on the opposite side, only a few remaining in the tract on the same side. Hence in the highest animals including man the optic tract consists of fibres from both optic nerves, chiefly however the fibres from the opposite side. Gudden claims that this is associated with the attitude of the eyes, so that in man as compared with the lower mammals the eyes are in a frontal position permitting of the union of the two fields of vision. In the crossing of the fibres there would seem to be two bundles of optic fibres in each optic nerve, a crossing a and non-crossing bundle, the former being larger. These optic fibres passing centrally form the optic tract which are divided in connection with the pulvinares, quadrigemina and geniculata externa. Passing through the central cells in these regions the path is continued to the occipital part of the cortical hemispheres, the fibres entering the occipital part of the internal capsule in connection with optic radiation. In the eighth nerve we have the auditory channel. The ganglion cells are found in connection with the cochlear ganglion which is connected with the cochlear branch of the auditory nerve and is connected functionally with the corti organ, the vestibular branch being found in connection with the semicircular canals which are associated with body equilibrium. These two branches are connected centrally in different ways. The fibres of the auditory nerve originate from the cells in the cochlear ganglia and the accessory ganglion, uniting with the cells of the acoustic tubercle, passing to the striae medullaries and then passing to the opposite side in co-

nection with the corpora quadrigemina, the interna geniculata and the thalamus through the internal capsule at the occipital portion in connection with the occipital regions of the first and second temporal gyri. The lateral nucleus of the thalamus is associated with the cortex cerebri on the same side. In the case of the olfactory the impulses pass to the olfactory bulb on the same side passing through the olfactory region to the anterior perforation, one part of the tract leading into the gyrus fornicatus and the other into the gyrus hippocampi. The afferent impulses therefore pass through the internal capsule to the cortex cerebri, all or nearly all of them passing through the thalamus except those reaching the cerebral hemisphere along the olfactory tract.

In connection with the cell combinations in the central nervous system some interesting points are brought out by way of contrast with the lower vertebrates in which the number of cells is very much less than that found in man and in which the organization of these cells is much less complete. Even in these lower vertebrates the spinal cord is not absolutely developed because it shows a very much more simple structure than that found in man so that throughout the entire central system there is a diminishing complexity as we descend the scale of vertebrate existence. It is true that the complexity of the brain becomes greater than that of the cord but the cord becomes more closely bound into a unit by means of the connecting fibre tracts which associate the cell groups as well as bind the brain more closely to the sense organs by means of the cord tracts. Hence throughout the entire central system in the development from the lower to the higher we find the principle of concentration becoming more distinct so that the inter-relation of the brain, spinal cord and peripheral system is more complete, while the parts become really at the same time more independent. In the lancelet which represents the lowest of the vertebrates in which we find neither brain, skull nor vertebræ, by dividing it in two and then placing it in the water the stimulation of the two parts produces locomotion similar to the intact animal. By cutting off the head of a shark the body will continue the regular movements associated with swimming. In the torpedo the division of the cord from the brain does not destroy the power of movement. In these and other similar cases found particularly among the different classes of fishes the separation of a part of the central system does not destroy the reactions given by a part, so that the parts seem to possess in a special degree independent power of response to stimulation. As we pass upwards in the vertebrates this primitive power of independent action seems to be lost or at least to a large extent diminished. This has an important bearing on the researches in connection with the localization of areas to be discussed later. It is found that very few of the regions of the central system consist simply of a single kind of cells with their branching neura and dendrons passing out and in. There are found in almost every region different forms of connection with other regions and there are also found different pathways of connection between other areas, these pathways passing through different regions. On account of this when any part of the central system is removed or cut off not only are there taken away certain cells but pathways are broken which interrupt the normal connections of different regions, resulting in disturbances of functional activity. On account of this it is impossible to determine the exact value of any part of the central system by experiments in the nature of division or extirpation. This is increased in the higher animals where organiza-

tion has been very fully developed so that as the centers and pathways become more completely and complexly combined in the formation of a unit the separation involves a greater amount of disturbance.

An important element in this connection is also found in the stage of development the individual animal, because at different stages this complicated relation is more or less complete according to the stage of development. By removing the cerebral hemisphere from a fish little interference is found in connection with its movements, coordination is not lost and the sense of vision is not impaired. If the cerebrum is removed from a shark it loses its movement entirely. It is found that by dividing one of the olfactory tracts little change takes place in the activity of the shark but by dividing the two it becomes entirely passive, because it has been deprived of the chief sensory impulses, namely, those of smell upon which it depends, so that even if only this pathway is cut off the same effects are noticed as if the entire cerebrum is removed, because the cord is severed from the cerebral cells which through sensory stimulation provide stimulation to the cord. In the case of the frog it is found that on removing the hemispheres it is capable of doing a great deal spontaneously, swimming and moving about quite freely, even feeding itself normally and preserving the power of equilibrium. By removing the optic thalami this power of equilibrium is destroyed. By removing smaller parts of the brain section by section there is found to be a gradual loss of certain movements, although coordinated movements can still be found in connection with the frog from which the larger part of the brain has been removed; only when the front limb movements have been interfered with by the destruction of the upper portion of the cord does the coordination become completely lost. Thus the gradual loss of the brain substance involves the gradual loss of the power of response, stronger stimulation being necessary to secure a reaction of any kind. In the pigeon, by removing the hemispheres including the basal ganglia, without interfering with the optic chiasm, it remains dull and apathetic for some days, this sleepy condition being interrupted and followed by the ability to walk about, its movements being guided by the sense of vision. It has still the tactile sensations and can preserve the body equilibrium. In the absence of the cerebrum pigeons do not feed voluntarily but if the frontal parts of the hemispheres are preserved they do preserve the capacity to feed themselves. All the stimulations from the external world seem to be similar in the case of the pigeon when the cerebrum is removed, no power of discrimination being noticeable.

In the case of the dog the removal of the cerebrum produces blindness, while a very loud sound was perceptible by arousing him from sleep and the sense of taste was distinctly preserved as was manifest from rejecting unsavory food, the tactile sensations awakened a very clear response in the attempt to remove the irritation. The dog still possessed the capacity of walking, standing, and eating, the muscular sense being the chief guide in these operations while all emotional and conscious feelings were entirely absent. It would seem that in ascending the scale of the animal life the removal of the cerebrum produces greater disturbance in the higher animals as compared with the lower, the effects being more likely to prove fatal and the effects being more permanent where partial recovery takes place.

This would indicate what the experiments bear out that the removal of the cerebrum in the higher animals destroys those functions which

characterize these higher animals as distinguished from the lower. The same results have not been found in man because experiments are not admissible in the human subject. There is no essential difference between the arrangements of the central system in the highest animals as compared with the lower animals. In the brains of some small brained idiots there is an absence of brain substance altogether out of proportion to the normal brain so that the same amount of brain loss in a normal individual would prove fatal. Hence there must be in the human brain the power of adaptation to loss sustained, particularly if this takes place early in life, so that the adaptation can take place gradually as life progresses. In the human subject the loss of part of the cerebral cortex representing the motor area is associated with muscle paralysis corresponding with the part affected. The efferent impulses passing from the anterior groups are made up of impulses coming from the posterior roots and being localized in the segment of the cord as well as impulses coming from the brain. In the lower animals these cerebral impulses are less important than in the higher animals in whom the cortex and the pyramidal tracts are fully developed, so that in the human subject the lesion affecting the cortex materially interferes with these impulses resulting in motion in connection with the muscles. In connection with the sensory regions the same principle is applicable, namely, that the higher the vertebrate is in the sphere of life the greater is the influence of the sensory impulses upon the reaction associated with the cerebral cortex. In regard to the other parts of the brain the complete division of the corpus callosum does not seem to result in any functional loss. The callosum is supposed to consist wholly of commissural fibres, no fibres passing to the internal capsule. Injury to the corpora striata does not affect either sensation or motion, although it does produce an increase of temperature. It has been found in the rabbit that the puncture of one corpus produces a rise of three degrees C. with a tendency to return to the normal again after a short period. In man where the lesion is found in the corpus it affects the opposite side of the body and produces dilatation in the regions of increased heat. The same results are claimed to follow a lesion in the optic thalamus although in a lesser degree. In the case of the cerebellum we find great variations in the vertebrates. It does not represent psychic activity. Its removal does not produce permanent paralysis, the immediate results being paralysis chiefly in the hind limbs. Great variations have been found in the effects produced by different leisions. The division of the two cerebellar hemispheres produces only a temporary interference with locomotion from which it is inferred that the important connections of these cerebellar hemispheres are with the cord and the other basal ganglia on the same side, while towards the anterior brain the connection is established by decussation. Each cerebellar hemisphere is connected in this way with the cerebellar hemisphere on the opposite side. The cerebellum according to this seems to form an intermediate organ in connection with the coordination of impulses that pass up to and down from the cerebrum, there being a double pathway in connection with the cerebellum both towards the cerebrum and the cord. In this way we find the close relation of the grouped elements in connection with the functional activity of the neural mechanism, this correlation of parts being more complete in the human subject. The most perfect grouping of neural cells is to be found in connection with the spinal cord and the brain which we are now to consider.

SECTION V. The Spinal Cord.

In the spinal cord we find the white and the gray matter, the white substance surrounding the gray matter. Anteriorly the cord is divided by the anterior longitudinal fissure into a right and left half and posteriorly by the posterior longitudinal fissure. Each lateral half is divided into columns by a furrow along the point of origin of the anterior roots. In this way we have three columns, the anterior, the posterior and the middle. In the lower cervical and the upper thoracic regions each of the posterior columns is divided into an inner and outer column, called the columns of Goll and Burdach. In the gray matter we find two lateral columns united by a commissure each half representing a rounded anterior horn and a pointed posterior horn. Laterally the anterior horn shows another horn called the lateral horn, particularly in the lower cerivcal region. The anterior roots arise from the anterior portion of the anterior horn and the posterior roots from the posterior horn. At the basal region of the posterior horn there is a network of gray matter the reticular process, behind which we find the Rolandic gelatinous substance. The central gelatinous substance also consisting of gray matter surrounds the central cavity; anterior to this central cavity we find the anterior commissure of gray matter and posteriorly the posterior commissure. In the cervical and lumbar regions the gray matter is more abundant than in the thoracic region. The white matter consists of medullated fibres of varying size, the anterior, lateral and lateral parts of the posterior column being the thickest; while in the gray matter we find both cells and fibers, the cells being multipolar ganglion cells, the polar neura forming axis cylinders for the medullated fibers. The cells may be single or in groups. These elements of the cords are bound together by connective tissue processes, continuing the pia mater, which pass to the cord along with the vasculation and encase the fibres in white substance. They are also bound together by means of the neuroglia which consists of a cement semi-fluid substance kindred in composition to keratin together with the flat nuclear neuroglia cells

The nerve cells are found in groups arranged in symmetrical form in the ganglionic columns of the gray matter. These cells consist of. (1) those in the anterior portion of the anterior cornua whose neura are continuous with the fibres of the anterior roots. This is called the motor ganglionic column. (2) A column of smaller cells in the middle portion of the cord from the third lumbar to the seventh cervical called the posterior vesicular column, the neura of which are continuous with the fibres of the lateral column. (3) A column of cells in the external part of the gray matter lying between the anterior and posterior horns called the intermediate lateral column. The fibres that pass to the striped muscles originate in cells of the anterior cornua while the visceral fibres arise chiefly in the posterior vesicular cells and also in the cells of the intermediate column. Gaskell says that the cells of the posterior vesicular column give rise to the inhibitory fibres of the alimentary, vascular and glandular systems; while the vaso-constrictors arise only in the thoracic region of the cord in connection with the posterior vesicular column. The motor fibres of the alimentary muscles originate at the base of the posterior horn, whereas, the motor fibres of the diaphragm, abdominal muscles and the muscles of the mouth arise from the anterior side of the intermediate lateral column, and the motor fibres of the vascular and glandular organs

from the small cells of the same column. The primitive cord consists almost wholly of gray matter, the columns being added later, the anterior and posterior, the anterior horns being distinctly divided off from the posterior. Along the sides of the spinal cord are the attachments of the anterior and posterior roots of the spinal nerves, some nerves from the anterior roots terminating in cells in the anterior horn, others crossing to the opposite side of the cord while others pass to the anterior portion of the lateral column and the posterior horn

The functions of the spinal cord are classified as four fold, (1) the function of transmitting impulses both motor and sensory. The spinal nerves have two root, connections namely the anterior and the posterior. If anumber of anterior roots are divided there results on the same side of the body paralysis of the muscles of motion. If the divided nerves are stimulated at the peripheral ends the muscles may be thrown into a tetanic state or only slight contractions may be found. No effect is produced upon sensation indicating that these anterior roots are true motor nerves. If the posterior roots are divided sensation is lost on the same side of the body and if the central ends of the divided nerves are stimulated the sensations become painful, indicating that the posterior roots are true sensory nerves. The roots form connections with the gray and white matter of the cord and as their branchings are very complicated they cannot be traced out with accuracy. The only method therefore of tracing out the connection is by the Wallerian method of degeneration. If an incision is made so as to divide the anterior columns leaving the posterior columns solid there are no voluntary movements in the parts below the division. If an incision is made so as to divide the posterior columns leaving solid the anterior columns, voluntary movement is weakened but not lost. If an anterior lateral column is divided on one side the voluntary movement is lost on the same side. This indicates that the motor fibres pass along the antero-lateral column from the brain and that these motor fibres pass to the same side of the body, at least in most cases. If the posterior column is completely divided sensation still continues in the lower part beneath the section although the coordination of movements is lost. If both the antero-lateral and posterior columns are divided it does not destroy sensibility; if however the posterior column alone is left intact sensibility disappears indicating the passage of sensory impulses through the gray matter. This is explained by the fact that the nerve fibres intersect each other in the gray matter. Brown-Sequard has shown that semi-section of the cord cutting into the gray matter weakens the sensibility on the opposite side, the loss of sensibility increasing as more of the gray matter comes to be affected. If the section is made vertically at the base of the posterior median fissure sensation is lost on both sides while by a lateral division sensibility is increased on the same side and lessened on the opposite side. The impressions produced in connection with touch seem to travel along the posterior columns. Where there is paralysis of these posterior columns the sense of touch is lost although the feeling of pain is not lost. In locomotor ataxia the first stage represents an interference with sensibility accompanied by darting pains in the back and limbs. This is followed by want of power to control the body including the loss of coordination and also the loss or impairment of the muscular sense. The final stage is represented by total paralysis. This is caused by a chronic inflamation in the region where the posterior roots join the cord and indur-

ation of the posterior columns, finally by slow degrees coming to affect the whole cord. This indicates that the sensory pathway is through the posterior columns, because in locomotor ataxia the unsteady gait is due to lack of sensory impulses that are necessary for the coordination of movement.

(2) The function of the spinal cord represents its action as a reflex center. We find reflex centers of movement in the cervical, thoracic and lumbar areas of the cord, the higher cervical region being associated with special activity representing particularly specialized movements. Stimulation may originate in any of the afferent nerves, the impulse passing to the cord and producing changes in the cells in the gray matter and resulting in the sending out of impulses through the motor fibres. This reflex action represents coordination between certain cutaneous regions through afferent nerves, centers and efferent nerves and the muscular regions of the body. So much specialization is found among these movements that often we find complete purposiveness in the reflex action. Reflex activity may be inhibited from the upper centers, hence, the removal of the upper part of the brain which increases the power of reflex stimulation removes the inhibitory action. The same effect may be produced by strychnine and opium and the opposite effects by aconite, chloral and ether. In tetanic conditions there may be an increased excitability of the cord to such an extent that the spinal stimulation may produce convulsions. In the spinal cord in the human subject the functional activity is performed in connection with nerve cells and nerve fibres. The nerve centers that are found in the spinal cord are arranged in certain groups corresponding with the work that is done by these centers, these collections of centers being found associated with the cord segments. The spinal cord activity is concerned in the functions that are associated with the visceral organs. It is not necessary for the performance of these functions that the brain should be in an intact condition the spinal cord with its collection and combination of nerve cells in groups possessing sufficient force to carry on these visceral functions. In general we find that such nerve centers are found in connection with the upper part of the spinal cord in connection with the activity of the heart, the lungs and the alimentary canal. At this point also we find the mechanism associated with the control of the calibre of the blood vessels, this mechanism operating through the lower centers found in connection with the different segments of the cord. In addition to this other centers are found in connection with the cervical enlargement the upper portion of the thoracic region and the lumbar enlargement which are concerned in the movements of the visceral organs, controlling not only the functions nf these visceral organs but also regulating the blood supply in the viscera, this being particularly the case with the lumbar centers. These nerve centers are more or less completely connected together by means of fibres of a commissural nature. Each half of the cord represents a half of the body so that each half of the cord represents a chain of ganglia controlling that portion of the body. Special reflex centers have been localized in connection with the spinal cord which are of special importance in connection with Osteopathic manipulations. A spinal centre for the cilium the cilio-spinal center connected with the iris movement between the sixth cervical and the third thoracic nerves has been localized. Stimulation of this area results in the distension of the pupil. The fibres which regulate the fibres of radiation in connection with the iris arise at this point. Accelerating centers are

found in connection with the sympathetics, the stimulation of which increases the heart's action. Respiratory centers have been found which govern the reflex actions of the thoracic and abdominal muscles. If the cord is divided above the eighth thoracic the abdominal muscles become paralyzed. If divided above the first thoracic the intercosal muscles are paralyzed. If divided above the fifth cervical the serratus magnus and the pectoral muscles become paralyzed and if divided above the fourth cervical paralysis of the diaphragm follows in connection with the paralysis of the phrenic nerves. There are also centers in connection with the limbs both upper and lower, the upper part representing the adductor and abductor muscles of the upper limbs and for the flexion and extension of the lower limbs. In the higher part of the lumbar region there is an erectile center connected with the organs of generation, interference with which may temporarily interfere with or permanently destroy the generative power. The parturition center is found at the first and second lumbar vertebræ. Centers associated with the action of the sphincter ani and the bladder are found in the lower thoracic and lumbar regions the destruction of these involving paralysis of the bladder with loss of power to retain the urine; the vesiculo-spinal center is about the fifth lumbar and the ano-spinal a little higher up. Perspiration centers are found at the third cervical for the front limbs and at the ninth and tenth thoracic for the hind limbs of the cat. In the frog there are lymph centers at the second thoracic and the seventh thoracic, these centers controlling the rhythmic contractions of the mesenteric lymphatics. Vasomotor centers exist in the different parts of the spinal cord, one vasomotor center being found at the lower end of the thoracic region.

Some reflexes have a value in diagnosis. Cutaneous reflexes (1) produced by the irritation of the soles of the feet, resulting in the flexion of the foot and toes and the drawing up of the foot towards the body. Here the center is in the lumbar region. (2) By pressing upon the internal surface of the thigh or on the internal condyle the cremaster muscle contracts resulting in the elevation of the testicle on the side of the compression. Here the center is found at the region of the first and second lumbar nerves. (3) An abdominal reflex is gained by pressing on the abdominal surface resulting in the contraction of the abdominal muscles, the center being found in the cord between the eight and ninth thoracic nerves. (4) By stimulating the body surface between the fourth, fifth and sixth intercostal spaces there is a contraction of the rectus abdominis, the center being found between the fourth and eight thoracic nerves. (5) By irritating the superficial surface of the body over the scapula contraction of the shoulder muscles is found, the center being found from the seventh cervical to the second thoracic nerves. Reflexes associated with tendons are found, if one leg is crossed over the other and a sudden mechanical blow is given to the tendon extensor below the patella; by flexing the leg on the thigh and striking the tendo Achillis the muscles of the leg calf will be extended; if the leg is flexed at the knee and the foot extended, and then the foot is suddenly flexed, rhythmical contractions of the muscles of the calf of the leg producing rhythmical flexions and extensions of the foot are found. These reflexes depend upon the spinal centers and if the centers or nerves are affected these are imperfect or lost.

Reflex action represents one of the great principles underlying the function of the central system. On the basis of this reflex action there is a mechanism providing for the response to sensory stimulation in the

form of some kind of movement. In the nerve center we find an afferent part which receives the impressions; a common meeting place which unites the afferent portion with the efferent portion of the center. In connection with the posterior horn we find the afferent channels entering the cord, so that we find the mass of fibres associated with a number of nerve corpuscles ramifying into very minute branches. On the efferent side of the nerve center we find large corpuscles which give off numerous branches, one process known as the axis cylinder process giving off a few branches and then passing out as the main root or anterior root of the spinal cord. In the central field we have the meeting place of the afferent and efferent, this meeting place representing the most important part of these spinal centers. The branches of the cells in the anterior and posterior horns approximate towards each other without meeting. It is difficult to understand how the junction takes place because there is no direct communication. Apart from the nutritive action of the spinal centers these centers are mainly concerned in arousing muscular contractions in response to irritation from a sensory stimulation. There is a difference in the discharge of impulses depending on the stimulus, slight stimulation not evoking a response so that the stimulus must be of adequate strength. By a single stimulus there is a single resulting twitch, while if the stimulus is continued there is tetanus, the entire center in this case having the power of summing up stimuli so as to give an adequate muscular contraction.

Horsley and Gotch say that during the passage of the nerve impulse there is a negative variation or a current of action. As to the amount of energy given forth by a center there is no means of measuring it although electricity has been applied to measure it approximately. By causing a nerve center to give out energy and observing the deflection in connection with the galvanometer we can get the amount of variation indicating the intensity of the nerve energy. Hence by exciting a nerve there is found a deflection of 200 to 300 in the galvanometer, while in stimulating a center and allowing the discharge to take place down the nerve the variation is only about 26 or 30. Here we have the basis for a physical estimate of the force of a nerve center. One of the most interesting points in is regard to the time occupied in transferring a sensory into a motor impulse. By taking a nerve leading from the cord to a muscle and making it lift a lever in connection with the breaking of an electric current and by stimulating some afferent nerve leading to the center with a single shock the center will convert the afferent into an efferent impulse. Helmholtz estimates the time occupied in the nerve ending in the muscle at .01 of a second, the nerve plate inducing the muscle contraction; the rate of impulses along the nerves both motor and sensory is about 34 meters per second. Hence, Horsley estimates that .006 of a second is occupied in the center in this conversion process, while Exner has estimated it at .06. But this difference may be due to the different conditions found associated with the stimulation.

(3) The spinal cord represents a center of automatism. In the case of respiration we have the most characteristic of all the automatic actions in connection with the alternate expansion and contraction of the lungs and the chest, in connection with the rhythmic discharge from the nerve centers. But along the spinal cord we find centers of automatism which represent the activities of the body organs, keeping up the tonicity of muscles and preserving the rhythmic character of contractions and relax-

ations. These actions are carried out by these centers under external stimulation; yet while this is so the nerve centers are in a sense independent, sending out impulses rhythmically manifesting their independence in the summing up of stimuli and in the periods during which energy is discharged. This automatism is undoubtedly found in the spinal centers. What takes place in connection with these centers when they have been stimulated? When the contractions of the muscles are traced out on the kymograph it is found that after the response to a central stimulus is given in the form of a contraction several rhythmic contractions follow which may be called secondary contractions, these contractions being really after results. This takes place in connection with the spinal centers equally with the cortical centers. This is particularly the case in diseases of the spine where on stimulation the centers continue to give forth energy after the stimulation is removed. Thus we find in connection with the ankle reflex, when the leg muscles are quickly extended there results a series of rhythmic discharges from the centers in the spinal cord producing a continuous movement of the foot. This is used in connection with this diseased condition as a diagnostic sign.

Automatism implies that changes arise in connection with the center itself and these are determined by conditions which are not found outside but inside the center. In the case of the brainless frog the body remains motionless unless stimulated; in the case of a dog after the spinal cord is divided there are found spontaneous movements under the control of the lumbar region. After the animal has recovered from the injury the hind legs are in constant motion moving about in a restless manner; if the animal is suspended from the front part of the body the hind limbs move rhythmically, indicating the discharge of rhythmic automatic impulses from the cord. In the case of the heart the seemingly automatic rhythm depends undoubtedly on the nutrition of the cardiac substance producing molecular changes; in the case of the respiratory rhythm it is dependent on nutritive changes in the center depending on the blood supply, especially when these are accentuated by the nutritive impulses entering the center from the vagus nerve. In the automatic action of the cord we find its fundamental basis in the nutritive changes taking place in the gray matter, the metabolism associated with the gray matter arousing impulses although these impulses are dependent on the impulses that come in from afferent sources Thus the automatism of the cord depends on intrinsic molecular changes under the regulative influence of extrinsic impulses. This furnishes the reason of the great limitation of the cord automatism as compared with the brain in which we find intrinsic nutritive change giving rise to almost numberless influences that originate impulses. The maintenance of the arterial tone in connection with the muscular coatings of the blood vessels depends on the automatism of the cord, the vaso-constrictors exercising a constant tonic influence so that even when the cord is cut off from the brain the vessels of the hind leg of an animal can be kept in tone by the thoracic and lumbar regions of the cord. In the unstriped muscle of the cardiac and pyloric sphincters of the stomach and the bladder and anus sphincter we have the maintenance of tonicity in connection with the spinal cord. Does the spinal cord exercise automatic influences over the skeletal muscles? In the section of a motor nerve it is said by some that no immediate loss of tonicity is observable as is found in the case of the division of the vaso-constrictors, so that they conclude there is no skeletal muscle toncity. The skeletal muscles, however, are in a

condition of tension so that if the attachments of the muscle are divided it shortens indicating that the tendency to shorten is counteracted by the muscle attachments. In the case of the skeletal muscles there are certain molecular changes going on in connection with nutrition so that the muscle retains its power to contract when the tension yields and so that when the tension increases it relaxes. As a result of this the muscles maintain their normal length returning to it after both contraction and tension. It is this that is spoken of as muscle tone in the skeletal muscles, the fundamental basis of it being the molecular changes taking place in connection with nutrition. As soon as the muscle dies this is lost as the nutrition of the muscles is governed in some way in connection with the central system, because by severing the nerve which supplies the muscle nutritive changes take place of a definite character. In a diseased limb as compared with a healthy one we find the loss of that resistance which is found in a sound limb. This skeletal muscle tone can be sustained in animals by the cord apart from the brain. After dividing the cord of a frog from the brain the muscles become soft and toneless; but after the injury is recovered from the muscle tone returns; if the animal is suspended by the fore limbs the hind limbs manifest rhythmic movements which must arise from the cord, as on division of the sciatic these movements entirely cease. In the case of a dog after the cord is divided in the dorsal region the hind limbs become soft while the shock continues but the tone returns when the effects of the shock pass off. In the human subject where the muscle tone is lost through injury or disease to the cord it is found that the muscle tone does not return fully in the region controlled by the cord below the lesion. Hence it is concluded that the spinal cord exercises as one of its functions an influence over muscles which preserves in them tonicity, but this influence of tonicity depends on the existence of sensory impulses as well as the intrinsic nutritive variations. That this is so is proved by the division of the sensory nerves in the case of a brainless frog, the cord ceasing to send out tonic influences. This has led some to speak of this as a reflex function rather than automatic. It is however rather automatic because there seems to be a combination of the intrinsic and extrinsic elements in the production of this tonic condition of the muscle. Pathological conditions tend to confirm this view. In certain diseases affecting the cord the legs become rigid in a condition of extension, the rigidity being complete in both limbs. This rigidity depends upon the continued contractions of the extensor muscles to such an extent that it becomes an abnormal tonic contraction. Sometimes this tonic condition is replaced by a clonic contracted condition. These contractions are undoubtedly carried out in connection with the spinal cord and are different from an ordinary reflex. In normal movement the extension is brought into play when the limb is in a flexed position, not in an extended position. In the diseased condition of the cord the opposite takes place, the extension being at a minimum in connection with the contraction. This seems to indicate according to Foster that when the gray matter of the spinal cord becomes diseased there is the arousal of latent impulses which come into operation in connection with these contractions. This is used as a diagnostic sign of a diseased condition.

In connection with the spinal nerve centers the efferent cells are small, the ramifications of the cells being lost in the spinal cord. In what way the impulses pass through the meeting ground to the large cells of the afferent part of the centers is not known. The question arises, which

of these three elements provides the neural energy. The large cells have been usually regarded as the source of this energy. Bastian tried to prove that the origin of the nerve energy is to be traced to the small cells on the afferent side, claiming that no evidence can be produced of nerve energy originating in connection with the large efferent cells. He claims that the fundamental basis of all motion is to be found in the sensory element which furnishes the element of retention in connection with former motions so that the memory of former movements forms the basis of all active movements. Bastian used kinaesthesis to represent the two-fold idea, (1) that all efferent activity originates in the sensory energy, and (2) that the basis of all movement is to be found in sensory memory. Horsley and Gotch have applied these ideas in connection with the electrical methods of investigation. They found that the stimulation of the spinal centers passed up along the cord as a series of impulses moving along the posterior and not along the anterior column. They also found that the nerve energy discharged from a center when excessive passed down along the posterior column and along the posterior roots as well as along the anterior roots. This was in line with Horsley's idea that the central cells presented an obstacle to the passage from the afferent to the efferent cells so that in reaching the efferent cells the impulses were greatly diminished in force. In finding out that the overplus of energy passed down along the posterior side they claimed that the origin of the nerve energy was to be traced to the afferent cells. By the use of electricity applied to the anterior roots of the spinal cord and by connecting the upper part of the cord with the galvanometer it was found that no current passed up along the spinal cord, indicating the extreme obstruction found in connection with the central cells. From these points of evidence Horsley concludes that the origin of the nerve impulse in connection with the center is to be traced to the afferent cells. Pfluger formulated a theory in connection with the reflexes that is in line with this. According to him when a sensory impulse passes along a sensory nerve reflexion takes place along a nerve belonging to the same segment. If the nerve fibre stimulated forms a part of the cord there is a tendency on the part of the impulse to move upwards, stimulating the centers one after another, until it reaches the bulb when the stimulation ceases or passes over to the other side. On the other hand on the stimulation of a cranial nerve fibre the tendency is for the stimulation to pass downward rather than upward toward the bulb. Hence he concluded that the spinal centers represent a more connected pathway for the passage of impulses upward than for their passage downward.

(4) The spinal cord also acts as a center for trophic influence. In the anterior horns are cells which have a trophic relation to the muscles. When the cells atrophy or degenerate the muscles become soft. It is claimed by some that the cells in the posterior vesicular column are trophic in their influence upon the visceral organs. These cells are different from the other cells of the cord, being bipolar, these cells being found only where the nerves leave the cord and control the viscera. This indicates that there are trophic cells for the viscera. The reflex actions of the cord may be inhibited by the centers in the brain. The single reflex can be gotten only when the brain is cut off. If the brain is cut off then the reflex excitability of the spinal cord centers is increased. If the body of a decapitated reptile is placed in a pendent position rhythmic movements are found depending on reflex action. In the case of the center of

micturition which is a reflex center impulses passing from the brain to the lumbar region of the cord may inhibit its action. In the dog after the division of the spinal cord in the dorsal region, micturition which is set up by abdominal pressure may be inhibited by pressure in connection with the sciatic nerve. In the human subject emotion has an inhibitory effect over the micturition center.

In each segment of the cord taking the vertebra as the unit we find a pair of nerves one on each side, these nerves passing out from the spinal canal in which the spinal cord is encased through the vertebral foramina. In the cervical region there are eight cervical nerves corresponding with the foramina; in the thoracic region we find the dorsal nerves originating these becoming as they pass out between the ribs the intercostal nerves; in the lumbar and sacral regions we find the corresponding nerves originating in connection with the lumbar enlargement of the cord supplying the viscera and uniting in the formation of the great sciatic trunk that furnishes innervation to the lower extremities. In connection with the spinal cord on the basis of the functions we have already described we find that the spinal centers are regulative of (1) motion. This represents the most important action of the spinal nerve centers. In order to understand these movements it would be necessary to follow out the analysis of the muscle relations with the spinal cord, but this is not necessary in the case of the individual muscles because all movements are more or less similar. In regard to the centers which are associated with the muscles the localization of movoment is made out in connection with the different parts of the upper and lower extremities, these parts corresponding with the segments of the cord. Hence the movements are determined on the basis of the cord divisions. Ferrier first found out that in the spinal cord of the monkey the cervical and lumbar enlargements represented the nerve centers for the muscle groups that regulated the movement of the segments of the limbs. Others who followed have indicated that the spinal cord is divided into segments, corresponding with the segments of the limbs so that the upper parts of the limbs are represented by the upper centers in the spinal cord and so on down to the lower parts of the limbs which are represented by the lower centers in the spinal cord. For example, in the case of the upper limb that part of the cord which contains its centers is found to extend from the fifth cervical to the first dorsal. The fifth and sixth nerves regulate the shoulder joint movements, while the eighth cervical and first dorsal regulate the thumb movements. The center arrangement for determining the character of motion follows the same plan. For example, the flexion of the upper limb is regulated by the upper part and extension by the lower part of the cervical region. The centers in the thoracic region as compared with the cervical and lumbar enlargements are smaller and less important because the muscles supplied by them, namely, in connection with the ribs are much more limited in their activity than the upper and lower limb muscles.

(2) Sensation. In connection with the nerve centers of the spinal cord a proper channel is opened up for the transmission of sensory impulses. These impulses have a special channel through which they pass and also certain points in the spinal cord where they are gathered together and arranged before transmission to the brain. By dividing the limb into a posterior and anterior portion the sensation in connection with these two parts will represent different portions of the spinal cord according to the point at which they enter the spinal cord. In connection with

the afferent impulses that come from the portions of the body which are in active motion as for example, from the muscles, tendons and joints when in action, these impulses representing what we call the elements of the muscular sense, form the basis of the delicate movements that are associated with the equilibrium of the body. In connection with the spinal cord they leave aspcial importance in connection with the upright posture. In the loss of consciousness the body standing will change the erect posture because of the inactivity of the muscles in connection with the centers in the spinal cord. If the muscles do not contract the joints will become relaxed and hence the body will be unable to maintain its erect position. In addition to this entire disorganization of the normal condition there are diseased conditions which affect only particular fibres and in connection with these fibres only particular sections of the spinal cord, so that the muscular sensations are cut off from certain regions of the spinal cord. It is in such conditions as these that the individual although he is able to maintain the erect position does so in a staggering manner, as we find it in connection with the condition of locomotor ataxia and in the condition of tabes which represents a gradual and propressive degeneration. Hence it is necessary in order to maintain the harmonious organization of the body system that these spinal centers receive the impulses of sensation in connection with the muscular and tactile centers.

(3 Muscle tonicity. In connection with the spinal centers muscle tonicity is preserved. In connection with the lower forms of life such as the medusaea condition of tonicity is preserved by the nervous system. In the higher animals the muscles are preserved in a tonic condition by means of nerve impulses so that if these impulses are cut off the muscles relax. These impulses cannot be sent out from the centers if the afferent paths are interfered with or cut off. By the division of the posterior roots the muscles that are supplied in connection with the centers whose posterior roots are cut become relaxed. The same thing is true if the anterior roots are divided. The existence of this muscle tonicity is essential to the functional activity of the muscles because the muscle contraction depends upon this tonic condition of the muscles. In the case of infantile paralysis in which the afferent cells seem to be either diseased or atrophied there is a loose condition of the muscles which indicates the absence of tonicity. (4) The blood vessels are also kept in a tonic condition by the nerve supply that emanates from the spinal centers. Here we have the vasomotor action upon the blood vessels. In connection with the blood vessels there is a constant variation in the calibre of the vessels, this variation depending upon rhythmical contractions and relaxations. Bernard found that by sending afferent impulses to the spinal centers the arterial walls may be relaxed permitting of a larger supply of blood; different impulses may lead to the constriction of the arterial walls. Here we have the basis of dilatation and constriction associated with the spinal centers, the fibres which are associated with this function in connection with the blood vessels emanating from the spinal centers. In some animals as for example in the serpent, if the nerve fibres which represent vaso-constriction are divided there is a very extreme distension of the blood vessels in the abdominal region, so that a large supply is found at this point, so large indeed that the blood may be kept away from the lungs and the upper parts of the body producing death. These minute centers which regulate this function of vasomotion are found all along

the spinal cord in connection with the different centers, particularly at the upper part of the thoracic region and the point in the lumbar enlargement from which the first three lumbar nerves originate. (5) Another special function of these spinal centers is to send out impulses which regulate the secretory processes in connection with the different glands of the body so that glandular secretion is subjected to regulation in connection with the spinal centers.

In regard to the posterior ganglion there is no evidence that it may be the center of reflex action or that automatically it can originate efferent impulses. The nerve cell bodies are different from the processes of the cells although these are really part of the cells. It is certain that some poisons act more sensitively on the cells than on the processes. The ganglion is in some way connected with the nutrition of the nerves. The growth of the efferent and afferent fibres takes place in opposite directions so that they are controlled by different trophic centers, the afferent fibres developing away from the ganglion towards the periphery or spinal cord. The efferent fibres grow out from the spinal cord peripherally. The fibres of the posterior root have a strong hold on the spinal cord, some fibres extending throughout the whole spinal cord entering the medulla passing along the side of entrance into the cord. Others pass along the posterior column entering the gray matter either above or below the point of entrance to the cord and either on the same side or on the opposite side. Thus an afferent impulse may pass along the posterior root to the cord and may produce results either above or below the point of entrance, while others pass along the whole length of the cord before any results may be found and may even pass into the medulla before any resulting action takes place. By the method of degeneration it has been found that certain fibres originating as processes of cortical cells pass to the medulla through the crura, decussate in connection with the pyramids and pass through the lateral column of the spinal cord forming the crossed pyramidal tract in connection with the thoracic portion of the lateral column, passing along the whole length of the cord. It gradually diminishes as it passes downward on account of fibres passing out from it so as to form the anterior roots. In this way impulses leaving the cortex crossing to the other side in the medulla and passing along the cord on the same side affect the body on the side opposite to that of origin. Other fibres leaving the cortical cells do not decussate in connection with the pyramids but pass along the same side of the cord forming the direct pyramidal tract which only appears in the upper portion of the cord.

In connection with the spinal cord Gowers makes out a tabulated list of centers in connection with superficial reflexes, (1) the interscapular reflex resulting in the contraction of the muscles attached to the scapula from the sixth cervical to the first dorsal; (2) the epigastric reflex which arises from stimulation of the anterior part of the skin between the fourth and sixth ribs in connection with the fifth, sixth and seventh dorsal; (3) the abdominal reflex consisting of the contraction of the abdominal muscles from the eighth to the twelfth dorsal. The absence of this reflex on both sides is taken as a diagnostic sign of extended disease of the brain while its absence on one side indicates the affection of the brain on the opposite side of the head; (4) the cremaster reflex in connection with the first, second and third lumbar; (5) the gluteal reflex consisting of the contraction of the gluteal muscles in connection with the fourth and fifth lumbar; (6) the plantar reflex in connection with the first, second,

third, fourth and fifth sacral. (7) The vesical reflex in connection with the first sacral, the rectal reflex in connection with the second sacral and the genital reflex in connection with the third sacral.

Physiologists are not agreed as to the excitability of the spinal cord in connection with artificial stimuli. Brown-Sequard claims that to apply stimulation either to the white or gray matter produces neither movement nor sensation. According to Schiff the spinal cord does not itself respond to stimulation but produces sensations. His views may be summarized as follows: (1) The sensory fibres of the posterior roots in the posterior columns produce sensations of pain but the posterior columns of the cord do not produce such painful sensations. He finds that the removal of the posterior column results in the loss of the tactile sensation and its stimulation produces dilatation of the pupil while the sensation of pain in both cases remains intact. (2) He finds that the anterior columns cannot be excited as long as the stimulation takes place direct, but there may be resulting movements in connection with the stimulation of the anterior roots. According to Schiff the stimulation of an uninjured cord takes place either in connection with the anterior or posterior nerve roots. This view of Schiff is opposed by Fick who claims that the cord can be directly stimulated, as he found by stimulation of the white columns of the cord there were resulting movements. In the case of the vaso-constrictors that pass down the lateral column of the cord these may be excited by all the stimuli which come to them along their path, the direct stimulation of the fibres in a transverse section of the cord producing constriction of the blood vessels that lie below the point of section. Similarly the ascending fibres in the cord may be stimulated so that the vaso-motor center is excited without producing sensation. The spinal cord may be stimulated directly by the application of NaCl or fresh blood to the cut surface. The motor centers of the cord may be directly stimulated by blood above a temperature of 40 degrees C. or by excessively venous blood or even by cutting off the blood from the cord by ligature of the aorta. In the case of unilateral section of the cord or section of the posterior column hyperæsthesia results on the same side of the body beneath the point of division; to such an extent is this the case that animals in this condition scream at the slightest touch. On the other side the sensibility is permanently lessened.

In connection with the spinal cord some work has been done in the localization of conducting paths. In connection with the posterior root the internal portion is supposed to convey the impulses from tendons and those in connection with touch and the localization of space. In diseased conditions of the external part of the posterior column such as is found in locomotor ataxia, the deeper reflexes are diminished and may even be destroyed. In the external fibres we find the paths that lead into the gray matter of the posterior horns carrying the impulses of temperature and the skin impulses of pressure and contact. The central fibres which enter directly into the gray matter carry the sensations of pain. The tactile sensations including pressure, temperature and the muscular sensations are borne upward along the posterior roots of the ganglia in connection with the posterior horns passing into the posterior columns on the same side. In the human subject the impulses from the legs pass along the Goll tract while the arm impulses pass along the anterior column ground bundle. The impulses in connection with voluntary movement are carried along the same side in connection with the anterior and lateral columns

and in the pyramidal tracts. The impressions enter the anterior horn cells passing to the anterior roots from these cells. In the lower dorsal region in connection with the rabbit these impulses have been found to be limited to the lateral columns. In connection with the reflexes originated by the tactile sensations the impulses pass into the posterior roots entering the posterior horns. The ganglia cells which are exercised in the coordination of reflex action are united by means of fibres which pass along the anterior paths, the anterior ground bundle and possibly along the cerebellar tract. In locomotor ataxia we find a degenerated condition of the posterior columns resulting in interference with motor action. There is not an interference with the voluntary movements but there is a lack of adjustment and coordination which depend upon the impulses of touch and the muscular sensations that are found associated with the posterior columns. The mantaining of equilibrium depends on the impressions that pass inward to the centers of coordination in connection with the central nerves so that any interference with the deeper or more superficial of these sensations interferes with equilibrium: for example, in locomotor ataxia, if a person closes the eyes and puts the two feet together it will be difficult to manitain equilibrium because of the cutting off of sensations in connection with the optic nerve, because the other weakened impulses are too feeble to be capable of securing coordination. When the tactile reflex sensations are inhibited this inhibition takes place in connection with the anterior columns, the impressions passing from the anterior columns to the gray matter in which they become united with the reflex mechanism. The sensations of pain pass along the posterior roots entering the gray matter, after which decussation takes place. Injury to the gray matter does not stop the conduction of the sensations of pain although they may be enfeebled; if however the gray matter is completely divided then the painful sensations are interrupted, producing the analgesic condition. It is claimed that in the case of the use of chloroform, if the condition of narcosis is imperfect this is found as the chloroform acts much more quickly on the nerves that conduct painful sensations than on those which are associated with the tactile sensations, so that while consciousness may exist as to what is being done there is not consciousness of the pain associated with the action or operation. The entire gray matter takes part in the conduction of these sensations of pain so that if the impressions are strong the painful sensations are also strong, accounting for the fact that painful sensations may be radiated. It is in this way we account for the fact that an acute pain originating from a single point may be radiated over a wide area. In connection with spasmodic impulses originating spasms of movement the gray matter represents the path of conduction to the anterior roots as we find in epilepsy. In the case of wide reflex spasms the impulses pass from the posterior roots to the anterior horn cells from which they pass to the anterior roots either above or below the point of entrance into the cord. The vasomotor fibres are found in the lateral columns passing into the gray matter leaving the cord by the posterior roots, reaching the muscles either in connection with the spinal nerves or after passing through the rami communicantes in connection with the sympathetics. If the spinal cord is completely divided in transverse section there is complete paralysis of sensation and motion in all parts supplied by the nerves beneath the point of section. This does not interfere however with the tonic trophic condition of the muscles supplied below the point of section. Vasemotor paralysis is found below the

point of section although this is temporary because after a short time the subordinate vasomotor centers become completely established and in this way the blood vessels become tonic again. The voluntary control of the parts below the point of section is cut off, although the actions of micturition and defaecation soon become purely reflex in this condition. If the section of the cord is unilateral there is paralysis of the voluntary muscles of the same side that are supplied by the nerves given off from the spinal cord. The muscles thus cut off do not become atrophied, but as soon as the degeneration of the nerves takes place they become rigid. The vasomotor paralysis is found on the same side as the lesion, but this does not continue below the point of injury. There is complete anaesthesia and analgesia on the opposite side beneath the section on account of the fact that the sensory nerves when they enter the cord very soon decussate, although some fibres run up along the same side producing a diminished degree of sensibility in a small area at the level of the section. In the human subject we find hyperaesthesia in connection with the parts beneath the point of section.

There are thus two great pathways along the spinal cord from the brain to the periphery, (1) the motor or efferent path originating in the cortex in the region of the Rolandic fissure, passing along through the corona, radiata and the narrow isthmus of the posterior part of the internal capsule through the crusta of the crus cerebri into the bulbar pyramid, where the majority of the fibres decussate, passing out into the cervical part of the cord along the crossed pyramidal tract on the opposite side; while a few of the fibres about ten percent of them continue on the same side as the uncrossed pyramidal tract, these fibres gradually crossing in connection with the anterior white commissure and entering into the crossed pyramidal tracton the opposite side. The fibres of the crossed tract are gradually given off to the gray matter of the anterior horns in which they are divided into fibrils, uniting with the plexuses close to the nerve cells, the cell processes of which pass out in the anterior roots of the spinal nerves. Thus the crossed tract is gradually losing its fibres along the length of the cord, this loss being partly compensated for by the division of some of the remaining fibres, until the entire tract disappears in connection with the lumbar region of the cord. On the two sides thecrossed pyramidaltracts send out across the median line isolated fibres which reinforce the opposite tracts as recrossed fibres. This it is said is the reason why in the case of paralysis of one side of the body only there are some muscles that escape paralysis because they have become attached as sympathetic muscles to those of the opposite side in connection with those recrossed fibres. (2) The sensory or afferent tract along which some if not all the fibres from the posterior roots pass up along the series of nerve cells to the cortex cerebelli, the corpora quadrigemina, the optic thalamus and the cortex cerebri. Along the efferent pathway we find but one cell group, the efferent cells of the anterior horn, while in the afferent we find two cell groups, one in connection with the posterior ganglia and the other in connection with the medulla.

The afferent impulses that pass to the cord along the posterior roots may choose different pathways in their passage to the brain. (1) directly along the postero-median column. Passing along this path they will enter the nerve cells in the cuneate nuclei of the medulla; (2) directly along the cerebellar tract to the restiform body. Along this path they will very soon enter nerve cells in the cord in connection with Clarke's

column. (3) They may pass along the antero-lateral column reach to the nerve cells in connection with the lateral nucleus of the medulla; (4) they may pass across the median line in connection with the fibres that are found in the posterior gray commissure and after passing into one of the ascending tracts pass directly to the brain; (5) they may enter the gray matter and leave it at a higher level entering the white matter and passing thence either directly or on the opposite side to the brain. Pathology indicates that the decussation of the sensory fibres takes place chiefly in the spinal cord because where one lateral half of the cord is destroyed there is an increase of sensibility on the same side beneath the point of lesion and the sensibility on the opposite side is lessened. The afferent fibres do not decussate in the cord until interruption takes place in connection with the nerve cells. Horsley finds that on dividing the sciatic nerve and stimulating it centrally by electricity the negative variation passes over to the opposite side of the cord. In addition to this crossed reflex movements are found. In the case of the stimulation of the central end of the sciatic we find movements in eth opposite front limb indicating the decussation of the afferent impression in the lumbar region of the cord somewhere, passing up the cord to the point of level with the brachial plexus. Hence some of the sensory impulses decussate in the cord, the remainder in all probability decussating in the medulla. It is claimed by some that sensory impulses may pass along any path open to them. This is negatived by the fact that when certain lesions are found in connection with the cord there is a loss of some sensations without any, or with only a slight, interference with others. Here, evidently, the pathological condition is limited to a particular path. In locomotor ataxia, for example, degeneration is mostly associated with the posterior column, indicating the cutting off of both impulses which arise in connection with the tactile sensations and form the basis of the muscular sense as well as the foundation of the equilibrium of the body.

Head lays down the principle that a certain segment of the cord supplies a certain region of the visceral system and on this assumption has mapped out the spinal cord into areas corresponding with the functions discharged by certain organs, as follows: the heart, first to third dorsal nerve roots; the lungs, first to the fifth dorsal; the stomach, sixth to ninth dorsal; the intestines, ninth to twelfth dorsal; rectum, twelfth dorsal and second to fourth sacral; the liver and gall bladder, seventh to tenth dorsal; the kidneys and ureters, tenth to twelfth dorsal; the bladder, eleventh and twelfth dorsal, first lumbar, second to fourth sacral; the prostate, tenth to twelfth dorsal, fifth lumbar and first to third sacral; epididymis, eleventh and twelfth dorsal, first lumbar; testes and ovaries tenth dorsal; uterus, tenth to twelfth dorsal, first lumbar and second to fourth sacral. In connection with the reflexes these are made use of diagnostically as any diminution or loss of reflex action involves the alteration and loss of the power of conduction, even if the center continues to be intact. In locomotor ataxia, for example, the absence of the knee jerk indicates the diseased condition involving the posterior roots and the posterior column of the spinal cord, while the centers in the gray matter and the anterior roots are normal, at least in the initial stages of the disease. In cases of the inflammation of the gray matter of the cord there is a break in the central and efferent links while the sensory link in the reflex is perfect. In the case of a paraplegia involving paralysis of the lower extremities of the body when brought on suddenly by accident or resulting from chronic

diseased conditions, the reflexes become exaggerated on account of the cutting off of the inhibitory influence of the higher centers. In the case of degeneration associated with the lateral columns of the spinal cord there is an intensification similarly of the reflex action of the cord arising from the withdrawal of inhibitory influences or possibly due to the increased irritability of the gray matter of the cord itself. Experiments and observations join in demonstrating that the motor paths in the human subject pass from one side of the brain to the other side of the body by way of the lateral column on the opposite side and along the anterior column on the same side, the former representing the crossed pyramidal tract which crosses over the median line in the medulla and the latter representing the uncrossed pyramidal tract which is smaller and crosses the median line in the spinal cord. In connection with the sensory paths these cross from one side of the body to the opposite side of the brain, the principal crossing taking place according to the older view in the cord but according (to the more recent view in the medulla higher than the pyramidal decussation.

It is not possible to observe the reflex action as it takes place in the spinal cord in the normal condition. Hence if the brain and the spinal cord remain intact the reflex and the voluntary actions cannot be separated, so that in the human subject in normal conditions sensation and volition are so closely related together that they cannot be separated. The reflex actions that are associated with the spinal cord represent the unconscious attempt to defend and preserve the body. In the case of the decapitated frog in a pendent position by irritating one of its feet retraction of the limb takes place in connection with the action of the flexor muscle. After the irritation is withdrawn the limb is extended; if the irritation is continued the muscles will flex and extend until the spinal cord is exhausted. Here the flexor muscles are brought into activity in connection with the attempt to remove an irritation. If an irritation is applied to the side of the body the hind limb will move towards the point of irritation with the object of removing the irritation, indicating the adaptive character of the reflex movements. This does not depend upon any psychic function discharged in connection with the spinal cord because we know that when the cord is cut off from the brain by lesion or disease the parts of the body beneath the lesion cease to be sensitive and subject to volition. Hence the movement must depend upon the limb relation to the nervous mechanism found associated with the spinal cord. In the case of experiments made on decapitated individuals it was found that by stimulating the surface of the chest the arm was flexed and the forearm was moved inward, resulting in the bringing of the hand close to the point of irritation. It is evident from this that the sensory fibres are directly related to the motor fibres through the cells of the gray matter in the spinal cord which gives direct reflex action. These reflex movements associated with flexion are peculiarly adapted to protect the body and may result from slight stimulation; the movements that are associated with expansion and rotation seem to be adapted to warding off some foreign body or to the withdrawing of the body from some foreign substance and these depend for their activity upon an increased stimulation. By stimulating suddenly the surface of the body either mechanically or thermally there is often a quick spasmodic movement even before any sensation of pain is felt, so that the action must be purely reflex. If the equilibrium of the body is lost the limbs are found to be bent, indicating the attempt

of the body to protect itself from fall by breaking the movement so as to bring down the body with ease. These movements are performed altogether outside of the field of consciousness. One of the most important of the functions discharged by the spinal cord is in the preservation of equilibrium and in the guidance of body locomotion. In the maintenance of equilibrium many muscles are brought into play the body being balanced and preserving its equipoise without exhaustion. In the body movements the flexor and extensor muscles are associated together with peculiar adaptive power in the balancing of the body as the body is moved, calling into play the action of extensive muscle combinations. In the maintenance of equilibrium and in the guidance of locomotion the spinal cord requires the assistance of the brain because if the medulla is suddenly injured or if the upper part of the spinal cord is injured body equilibrium is no longer preserved. In some of the lower animals as in the frog the reflex action of the spinal cord is sufficient to preserve the body in balance upon the limbs but in this case the body seems to rest upon its limbs naturally. The decapitated frog according to some can be made to jump, each movement stimulating the limbs so that extension and flexion are promoted. In the higher animals and especially in man in addition to reflex action there is voluntary action. While the voluntary action is necessary in equilibrium and locomotion the subordinate part of these functions is discharged by the spinal cord. In other words when the action involved in equilibrium or locomotion has been originated the apparatus of the spinal cord may continue the action without any volition or intervention on the part of the will. It is not known in what way this is accomplished possibly it is because the reflex action of the cord keeps up constantly the tension and relaxation necessary for the equilibrium and locomotion of the body. Here there is required the harmonious action of the different parts of the spinal cord and this takes place through the longitudinal fibres that are found in the posterior columns. These fibres are found to run for a short distance in the posterior columns entering and leaving and then reentering the gray matter as they pass upwards forming a continuous tract throughout the spinal cord. At the margins of the gray matter and the white columns fibres pass in a slanting direction from the one to the other and this is found to be the case particularly in the posterior columns and in connection with the posterior horns. The posterior columns do not represent the pathways for sensibility or in connection with voluntary action. The division of these columns does not produce paralysis but if there are several divisions transversely at short distances locomotion is interfered with and there is the loss of muscular equilibrium.

Where injuries are found in the spinal cord there are found to take place secondary degenerations which may exist in different parts of the longitudinal columns. Some have claimed that these secondary degenerations are found to extend from the original injury towards the brain and never away from the brain peripherally. The internal part of these columns is found to consist of a narrow portion which in connection with the cervical region is distinct and separate from the rest of the column, this part being called the Goll column. On the external part of the posterior column the degeneration is found to extend centrally for a short distance, indicating that the longitudinal fibres close to the posterior horn are short and arise from the gray matter ending in gray matter a little above. In connection with locomotor ataxia we find an impediment in

walking interfering with the body equilibrium, so that the body equilibrium cannot be preserved normally without volition. Hence the locomotion is abnormal while the power of volition is preserved normally. This is evident from the fact that muscular strength can be exerted at will both in connection with the arm and the limb. In other words while the voluntary control is complete the involuntary element is weakened. In connection with this disease the posterior columns are found to be affected, this affection being found to be sclerotic, the connective tissue increasing while the nervous tissue has degenerated. If this condition is localized in a small area of the posterior columns voluntary activity is not interfered with; but if it is found to cover a large area either in the cervical, dorsal or lumbar region there is always an interference with volitional movements. This sclerotic condition of the posterior column is limited to the lateral parts, the disease in this case representing a primary change in the nervous system involving a greater or less extent of the nervous tissue.

From these facts it is evident that in the spinal cord there is definitely localized the involuntary power of muscular coordination which is particularly associated with the longitudinal fibres of the posterior columns. The spinal cord exercises an important control over the intestinal sphincters and the muscles of defaecation. The sympathetic supplies nervous connection to the small intestines, the colon and the caecum but the lower part of the rectum is innervated from the spinal nerves through the sacral plexus. The lower portion of the large intestines represents the faecal reservoir. When the faeces commence to pass from the lower part of the intestine there is capacity of retention in the rectum and also capacity of discharge, these depending upon the action of two sphincters, the spincter ani which has as its function the closure of the anal orifice, and then the levator ani which is associated with the contraction and opening of the anus. These actions take place under the reflex control of the centers in the spinal cord. Normally the spincter ani is in a condition of contraction hindering the intestinal contents from escaping. The closure of the sphincter is purely involuntary depending upon the reflex action of the spinal cord. On the distention of the rectum a stimulation is aroused which passes to the spinal cord arousing an impulse which is sent from the cord to the sphincter ani producing relaxation. Simultaneously the margins of the relaxed opening are drawn upwards by the action of the levator ani, permitting of the expulsion of the faeces. These actions are associated in normal conditions with more or less voluntary control, the voluntary control exercising an inhibitory influence until the involuntary impulse prevails when the discharge takes place in connection with the reflex function of the spinal cord. If the spinal cord becomes excessively irritable the discharge takes place purely involuntarily. If the cord is injured then sensibility and voluntary actions are absent the discharge being both involuntary and unconscious. If the lower part of the cord is injured then the normal contraction of the sphincter muscles is lost and there is permanent relaxation of the sphincter so that the power of retention is lost. The bladder represents a urinary reservoir and in connection with it we find the vesical sphincter. The nerves of the bladder are found to consist of sympathetic fibres in connection with the ganglia of the mesentery and the spinal nerves from the lumbar region of the cord, a union of these taking place in connection with the hypogastric plexus. The vesical sphincter is maintained in a condition of tonicity by involun-

tary nervous action. When evacuation takes place relaxation of the sphincter takes place by a voluntary impulse the contraction of the bladder taking place involuntarily. It has been found that by irritating the lumbar region of the spinal cord there is a contraction of the bladder, these contractions ceasing if the sacral nerve roots are divided. Similarly bladder contraction may be found by stimulating the sympathetic or spinal nerves entering the hypogastic plexus. If the spinal cord is diseased or injured there is found paralysis of the bladder, the contraction of the bladder being subject to the involuntary action of the sympathetic and spinal systems, the sacral region of the spinal cord exercising the most important influence.

The closing and opening of the vesical sphincter depends upon the spinal system. Experiments have indicated that the center of reflex action associated with the vesical sphincter is found in the lumbar region of the spinal cord. By dividing the spinal cord at the first or second lumbar vertebræ no variation is found in connection with the sphincter, but if the division takes place at the fifth, sixth or seventh vertebræ there is a lessened resistance on the part of the vesical sphincter. Hence it is concluded that the tonicity of the vesical sphincter depends upon reflex stimulation arising in connection with the vesical center about the middle region of the lumbar part of the spinal cord. Urine retention and evacuation may take place without voluntary action. Goltz found that by dividing the spinal cord between the thoracic and lumbar regions although there was a loss of sensation and voluntary action there was still the capacity to retain and evacuate the urine. In the human subject when an inflammatory condition excites the bladder sensitiveness there is an increase in the intensity of the reflex stimulation to micturition, resulting in the discharge of the urine just as soon as a small quantity is accumulated in the bladder. If the spinal cord is injured in the dorsal region all sensation and voluntary control of the bladder may be removed without interfering with the reflex act of micturition associated with the lumbar region of the cord. If the lower part of the spinal cord is injured or diseased there is often a paralytic condition of the bladder which prevents the normal reflex micturition process. In this case the urine will accumulate unless removed, being retained in connection with the elasticity of the bladder and urethra but after a time the resistance will be destroyed and the urine will pass away just as it is excreted from the kidneys.

Before leaving the spinal cord we must point out the connection of the spinal cord to the brain. The connections are established by means of the prolongation of the longitudinal columns through the medulla. This does not represent a simple continuation because the fibres from the different columns change their position in connection with the medulla and decussate. The larger part of the spinal cord is found to consist of columns of longitudinal fibres, each of the columns having a special form and position. In the upper cervical region there is found to be a difference, the fibres of the internal and posterior portions of the lateral column slanting inward as well as forward in connection with the anterior horn and posterior to the anterior column.

Above the second cervical the fibre bundles coming from the lateral column are found to pass upward and forward in a slanting direction crossing the median line to the opposite margin of the anterior median fissure. We thus find in the lower part of the medulla at the base of the anterior median fissure alternating fibres bundles, crossing from right to

left and from left to right representing the decussation of the anterior pyramids. When the decussation is complete we find two longitudinal fibre bundles close to the anterior median fissure making their way forward toward the tuberannulare The anterior pyramids do not continue the anterior columns of the spinal cord, the fibres springing from the lateral column on the opposite side forming in the lower part of the medulla a decussation. As these fibres pass from the lateral columns to the anterior pyramids close to the median fissure we find the change in the spinal cord as it passes from the cervical region to the medulla. In connection with the cervical enlargement we find that the spinal cord is very broad, this breadth being due to the fibres in connection with the branchial plexus which have united with the lateral columns, after passing through the gray matter of the anterior horn. At the upper part of the cord there is a diminution of the transverse diameter and an increase of the antero-posterior diameter on account of the fact that some fibres pass from the lateral column to the anterior portion of the opposite side. In addition to fibres from the lateral columns some fibres come from the posterior columns and the posterior horn to the pyramids. This alteration is found above the previous crossing and forms the upper decussation in connection with the pyramids; these fibres when they leave the posterior column and the posterior horns pass forward and internal, crossing over the median line in a slanting position and entering into the anterior pyramids. The continuation of these anterior pyramids is found in connection with the tuber annulare into the crura of which they form a part. This portion of the crus is found at the base of the brain the fibres passing forward and upward to the corpus striatum. The upper part of the crura consists of fibres which come from the anterior columns and the anterior portion of the lateral columns. The anterior columns are found in addition to the median fissure up to the point where the slanting fibre bundles decussate in connection with the anterior pyramids. In connection with the medulla they pass outward pass through the tuber annulare and are found in connection with the uppermost part of the crura from which they pass to the optic thalami. The other fibres in connection with the lateral column pass through the medulla and tuber annulare as well as the crura entering into the optic thalami.

The inferior crura cerebelli represent the prolongation of the principal part of the posterior columns of the spinal cord. At the point where these columns separate from each other in connection with the formation of the fourth ventricle they seem to pass directly on either side out of the cord into the cerebellum. There is a difference of opinion as to which part of the cerebellar crura is derived from the posterior column of the spinal cord. According to Meynert the majority of the fibres decussate within the medulla so that the right crus is formed from the fibres coming from the left posterior column and the left crus from the fibres to the right posterior column. According to this the connections established between the spinal cord and the brain represent, (a) the majorty of the fibres of the lateral columns and part of the posterior columns when decussation has taken place becoming the anterior pyramids extended superficially into the crura cerebri and the corpora striata. (3) The rest of the fibres in connection with the lateral columns along with the anterior columns enter through the uppermost part of the crura cerebri into the optic thalami. The majority of the fibres of the posterior column when decussation takes place in connection with the medulla, are found in con-

nection with the restiform bodies in connection with the cerebellum. Thus we have established a close relation between the spinal cord and the brain.

The chief function that is established by the communication of the brain and spinal cord is what may be called a cross function. Sensory impressions made on the skin of one side of the body pass through the spinal cord and reach the opposite side of the brain; the motor impulses that originate on one side of the brain pass through the spinal cord and are associated with the opposite side of the body. This is evident from the fact that injuries or disease involving the right side of the brain produce paralytic effects on the left side of body involving both sensation and motion. The transmission of voluntary impulses along the spinal cord takes place on the same side; for example, by making a transverse section of one lateral half of the cord there results the paralysis of voluntary motion in connection with all parts below the point of section on the same side of the body. The conclusion is that each half of the body gets the impulses of voluntary motion in connection with the pyramidal tract in the one half of the spinal cord. Where the pyramids decussate in the medulla there is a crossing of the fibres and therefore of the impulses so that an injury involving the motor tract produces varying results, these variations depending on the location of the injury. If the lesion is in the spinal cord paralysis takes place on the same side of the body, whereas if above the pyramidal decussation paralysis takes place on the opposite side; and if the injury is found in connection with the pyramidal decussation itself both sides of the body become paralyzed. This represents the three possible simple conditions of unilateral and bilateral body paralysis. In connection with the degeneration that is found in the pyramidal tract it is found that in addition to the fibres which decussate at the pyramids there are some fibres which pass down along the same side as direct fibres to the cervical region. It is not known where these fibres terminate although it is claimed that they end in the anterior horns of the gray matter giving off fibres to the upper extremities along which motor impulses pass to the extremities on the same side as the side of origin in the brain. Some physiologists claim that they pass through the white commisure in the cervical region and thus complete the decussation, all of the fibres being found on the opposite side of the cord to that of origin in the brain. In connection with these crossed and uncrossed fibres of the pyramidal tract it is claimed that variations exist in the number of fibres that cross and do not cross, depending on individual conditions.

In connection with the sensory impulses as they pass from the periphery to the brain through the spinal cord there is a similar decussation, as injuries to the brain higher than the medulla lessen or destroy sensation on the opposite side of the body. The sensory fibres differ however from the motor fibres in that they cross the median line at different points along the spinal cord. This is evident from the fact that if the spinal cord is divided transversely in one lateral half there is a loss of sensation in the opposite side while the sensation continues on the same side. According to Brown-Sqeuard this decussation of the sensory tract takes takes place entirely in the spinal cord. It is claimed however by others that this decussation of the sensory fibres is not complete in the spinal cord. When one lateral half of the spinal cord has been divided transversely there is the indication of the crossing of the sensory tracts, sensibility being entirely lost or greatly lessened on the opposite side, there

being on the same side an increase of sensibility with the loss of motor activity. The question arises what produces this increased sensibility? It is likely to be attributed to a local stimulation amounting almost to an irritation in connection with the gray matter of the spinal cord at the point of division, resulting in the increase of sensibility. The decussation of the sensory tracts can be plainly discovered by longitudinally dividing the cord in connection with the median line. If such a division is made in the lumbar region there is an entire loss of sensibility in connection with the hind limbs. In the case of the human subject it is found that injuries to the spinal cord result in the loss of movement on the same side and the loss of sensation on the opposite side. It is certain that the sensory and motor fibres have both completed their decussation in the medulla, the spinal cord beneath this being the conductor for the motor impulses and also the conductor as well as the seat of decussation in connection with the sensory impulses. In connection with paraplegia there is an affection of the spinal cord substance at a particular point resulting in the loss of sensation and movement beneath the point of injury on both sides of the body. If the injury is localized in the lumbar region the extremities and the entire pelvic portion of the body become paralyzed while the upper part of the body is not affected. If the lesion is found in the dorsal region the abdomen and thorax are included in the paralytic condition; while if the lesion is found in the upper half of the cervical region there is paralysis of the entire upper and lower extremities with the thoracic, abdominal and pelvic region of the body, In this latter case the paralysis is certain to prove fatal because the injury will involve the nerves that are essential for respiration. In hemiplegia we find the loss of sensation and motion in one half of the upper and lower extremities of the body involving the skin and the muscles of the entire lateral half of the body. In this case the injury is associated with the opposite side of the brain above the pyramidal decussation most commonly in the cerebral hemisphere of in the ganglia. In this case the loss of sensation and of motion are found in the same side of the body. If on the other hand the lesion exists in the spinal cord there is a loss of sensibility on the opposite side or the body and a loss of motivity on the same side. These paralytic conditions indicate the special function of the spinal cord in connection with sensory decussation and motor conductivity and impulses.

SECTION VI. The Brain.

It is not our purpose to enter the discussion of the anatomy of the brain as this does not belong properly to physiology. In the brain we find two cerebral hemispheres associated with what are called the cerebral ganglia, including the corpora striata, corpora quadrigemina, the corpora geniculata and the optic thalami, as well as the cerebellum and the medulla or the spinal bulb. Physiologically the medulla is rather spinal than cranial and the cerebellum although its function is supposed to be cerebral really represents the intermediate portion between the great spinal tract and the cerebral region. In connection with the cerebral ganglia their importance does not rest upon their possession of or performing any functions that can be specifically stated; but rather represent what is called the cranial isthmus representing the pathway of coordination between the cerebral hemispheres and the lower part of the nervous mechanism. From this standpoint the physiology of the brain

is largely limited to the cerebral hemispheres and to those parts which are called tracts that unite the hemispheres and form channels of connection between the different parts of the nervous mechanism. The brain represents a large mass of white substance in which is embedded gray matter and over which there is enveloped a gray substance layer covering over the enfoldings, fissures and convoluted parts of the surface. This superficial gray substance represents the brain cortex which is supposed to be associated with sensation and voluntary motion as well as the psychic functions. In connection with the white matter we find the sensory impulses as well as the motor impulses led in and out, so that it represents a conducting medium of massed fibres which appear in the front of a fan between the basal ganglia and the cortical substance, this conducting mass being extended into the lower part of the neural mechanism as the white columns of the medulla and the spinal cord. This white substance is spoken of as the corona radiata. In the basal portion of the brain we find this white matter forming itself into the internal capsule between the optic thalamus and the corpus striatum, representing the chief pathway in connection with sensory and motor impulses. Continuing this pathway we find the two cerebral peduncles passing through the pons Varolii continued out in connection with the white column of the medulla and the spinal cord. This principal pathway in connection with the white ma - ter receives and gives out fibres in connection with the ganglia through which and in the midst of which it passes at the basal portion of the brain. In what way the connections of these distant parts of the basal ganglia are united with these main tracts it is not nown, especially as these tracts represent mainly the pathway of sensory and motor impulses between the gray matter in the brain and the gray matter of the spinal cord. This has been demonstrated in connection with the degeneration of the efferent tract originating in the cortex, passing through the corona radiata, the internal capsule, the crura, the pons Varolii, the anterior pyramids of the medulla to the lateral column on the opposite side and the anterior column on the same side of the spinal cord.

In regard to the definite localization of the sensory and motor tracts pathology indicates that the posterior part of the internal capsule and the anterior part of the crus represent the chief paths of motor and sensory impulses. It is found that the lesion of the anterior part of the posterior portion of the internal capsule is found in hemiplegia; a lesion in connection wlth the posterior part in semi-anæsthesic condition. It is found by tracing the progress of degeneration in connection with the frontal and occipital cortical regions that they represent the anterior and posterior parts in connection with the pyramidal portions in connection with the capsule and crus. We find thus what is called a vertical fibre system and a horizontal fibre system, the latter being represented by the corona radiata between the two hemispheres in connection with the corpus callosum. The different convolutions found in the cerebral cortex are united together more or less completely by association fibres which have not as yet ben traced with any degree of accuracy. The vertical and horizontal fibre systems are represented by the internal capsule and the corpus callosum, both of these being closely associated together in connection with the corona radiata. From what has been said it will be evident that the cerebral hemispheres stand at the head of the entire neural mechanism and are in a sense independent not only of the rest of the mechanism but especially of the rest of the brain. This is evident from

the fact that in some animals the cerebral hemispheres may be removed while the animal may live for a considerable time. Interesting experiments have been made by the removal of the cerebral hemispheres in the case of the frog. Along with the hemispheres there are removed the corpora striata leaving the frog with the medulla, the cerebellum, the optic thalami and the optic lobes. In this condition the frog has been preserved in life a long time. In connection with the frog deprived of the cerebrum there is the absence of intelligence and volition. If the intermediate parts of the brain and the medulla are intact there is no interference with vasculation, respiration and alimentation and the animal is capable of moving although its movements require stimulation. It is claimed that such an animal will not move unless subjected to stimulation. In connection with the frog however as soon as the results of the injury have been recovered from there is a tendency to spontaneous movement indicating the adaptive power of the remaining portion of the nervous system. Under such conditions the frog does not give any evidence of the possession of volition although there is a difference between the frog simply with spinal cord and the frog which possesses in addition to the spinal cord the intermediate portions of the brain. In the latter case there is a capacity for movement when stimulation is applied so that a frog can freely swim and move about. If the stimulation is absent the frog will assume its normal position and if placed upon its back it will resume this normal position. The only difference seemingly is that the movements require external stimulation in order to call them forth. Another difference seems to be that they depend entirely on the stimulation, originating when the stimulus is applied and ceasing when the stimulation is withdrawn. If there is no interference with the optic nerves the movements seem to be regulated by the sense of vision. There is very little difference between this frog condition and the normal frog except in the fact that in the normal frog the actions and movements are volitional, whereas these are purely mechanical.

In the case of the warm blooded animals the removal of the cerebral hemispheres is a more difficult process. In the case of a pigeon the cerebral hemispheres have been removed and the animal preserved in life several weeks. As soon as the effects of the injury have passed away the pigeon resumes an almost normal condition as it is able to maintain its equilibrium although it will continue without motion and in a condition of stupor unless stimulated. Subjected to stimulation it may execute almost normal movements while in some cases, this condition of stupor passes away and it becomes capable of movements independent of stimulation. This condition of stupor is not due to the absence of the cerebrum but rather to the result of injury in connection with its removal. In the case of the higher animals it is very difficult to remove the cerebral hemispheres, although in the case of the rabbit the hemispheres have been removed, except the parts contiguous to the optic thalami; in such a condition the rabbit is quite motionless and does not exhibit any readiness to move unless when stimulated. It is claimed that in some cases the movements may be stimulated by light or by sound. In the case of the mammals there is undoubtedly a capacity of equilibrium and the capacity to execute movements in connection with the special senses when the cerebral hemispheres are absent. There is, however the entire absence of intelligence and of volition. In the absence of intelligence and volition there is the indication that these are associated with the cerebral hemis-

pheres.

In the medulla we find a more complex arrangement depending on the nerve fibres that pass through the grry matter and also the nuclei representing the new gray matter. It is the extension into the brain of the spinal cord connecting the brain proper and the cord so that the spinal medulla and the medulla itself from one organ. The spinal column is connected with the cerebellum and the cerebrum by means of the medulla. The gray matter of the medulla instead of representing the appearance of the cord is varied by the nuclei of the white matter, these nuclei being connected with the cranial nerve roots. The white substance of the cord changes its form and position when it passes into the medulla. There is a connection of each spinal cord column through the medulla with the cerebrum and cerebellum. In the evolution of the nervous mechanism it is found that the spinal cord about the fifth month of the embryonic life represents the pyramidal fibres in connection with the lateral columns the Goll and Turck columns as non-meduliated while the fibres connected with the anterior and posterior and the cerebellar fibres in connection with the lateral columns are medullated. It is claimed from this that the lateral columns represent the primative part of the cord while the other columns represent additions in the higher development of the spinal cord in the higher animals. The nuclei that are associated with the cranial nerve roots and which correspond with the anterior and posterior horns and the gray matter between these are as follows: (1) A nucleus for the hypyglossal, the motor tongue fibre; (2) a nucleus for an auditory nerve; (3) a general nucleus for the spinal accessory, pneumogastric and glosso-pharyngeal nerves; (4) a nucleus for the fourth nerve to the superior oblique muscle of the eye; (5) a nucleus for the sixth nerve to the external rectus muscle of the eye; (6) a nucleus for the facial nerve; (7) the corpus dentatum in which is found nerve cells although not directly connected with the nerve roots. In connection with the fifth nerve we find sensory and motor roots in connection with the medulla. In the third, fourth, sixth and hypoglossal nerves we find motor nerves in connection with the anterior horns; in the spinal accessory, pneumogastric, fifth and glosso-pharyngeal we find the mixed nerves in connection with the posterior horns and the intermediate gray substance.

The functions of the medulla may be summarized. (1) in connection with sensory and motor impulses. If the medulla is destroyed death will result because of the close relation of the medulla to the circulation, respiration and vaso-motor activity. The motor nerves from the brain decussate in the anterior pyramidal tracts passing down the lateral column of the cord through the anterior roots of the spinal nerves to the muscles. If the anterior pyramid is divided above the decussating fibres paralysis results in connection with motivity on the opposite side. Sensory fibres also decussate in the gray matter at the base of the posterior median fissure in connection with the spinal cord. Hence a blood clot in the left optic thalamus produces paralysis on the opposite side, both of sensation and of motion, that is, in this case we would have right side hemiplegia. (2) The medulla is the seat of reflex action. Various special centers are localized in the medulla, the respiratory center in connection with the pneumogastric nerves, consisting of an inspiratory and an expiratory part, the obliteration of which destroys respiratory action; the vaso-motor center which regulates the calibre of the small blood vessels in the body; the cardiac centers, an accelerator in connection with the sympathetic and

an inhibitory in connection with the pneumogastric, the deglutition center in connection with the sensory and motor nerves in connection with swallowing, the vocal center in connection with the sterno-cleido-mastoid muscle which is the regulator of the glottis action in connection with the expiratory process associated with vocalization the glycogenic center in connection with vaso-motor action upon the liver; the salivation center controling the facial nerves including the chorda tympani and the superficial pettrosal in connection with the glands of insalivation. The center which controls the facial muscles through the seventh nerve and mastication through the motor fibres of the fifth nerve; the sweat center in connection with and regulating the subsidiary sweat centers that are found in the spinal cord. In addition to these certain impulses pass to the medulla from the higher centers which may produce a modification of action of these medullary centers.

In the cerebrum and cerebellum we find an entirely different arrangement of the gray and white matter, although the structure is eventually the same. The gray matter found in the cortex cerebrum is an enlargement that covers the entire upper surface the corpora striata quadrigemina and the optic thalamus forming nuclei in the internal portions of the cerebral ganglia; in the central gray matter of the cord and the anterior of the ventricles of the brain out of which the cerebral nerves primarily arise; and in the cortex of the cerebellum. These masses of gray matter are united together by white fibrous tissue. The pons Varolii is above and anterior to the medulla between the cerebellar hemispheres. In it we find fibres longitudinally establishing connections between the brain and the medulla and spinal cord; transversely establishing connection with the lateral cerebellar hemispheres constituting the intermediate crura of the cerebellum. We find a number of fibre bundles; (1) an anterior fasciculus continuing from the motor cortical regions of the brain through the crural fibres and also continuous with the superficial part of the anterior pyramids of the medulla and with the crossed pyramidal tract to the opposite side of the spinal cord; (2) two middle fasciculi, the one continuous with the frontal cerebral lobes through the crural fasciculi and the other having fibres from the external portion of the crus descending to the lateral column of the spinal cord on the same side; (3) there is a posterior fasciculus continuing into the columns of Turck into the spinal cord of the same side; (4) there are commissural fibres crossing from one side of the cerebellum to the other; (5) a posterior fasciculus containing sensory fibres to the cerebrum from the medulla. Associated with these fibres we find nuclei of gray substance in connection with the cranial nerve roots, these nuclei representing the terminals of the facial nerve, the motor and sensory nuclei of the fifth nerve, three nuclei in connection with the auditory nerve and nucleus of the sixth nerve. Here we have established a nuclear connection with some of the nerve fibres that have nuclei in the medulla. In function the pons Varolii is a reflex center and also the medium for the conveyance of impressions. The motor channel is in the anterior portion. Motor fibres connected with the facial muscles decussate in the pons bearing impressions outward. If the lower portion of the pons is injured on the one side there is paralysis of the face on the same side and of the limbs on the opposite side. Rarely is there found a loss of sensibility and in these cases it is always on the opposite side. The sensations that are associated with touch, heat and pain are said to pass through the middle region of the pons. There

are numerous reflex centers associated with the pons representing complicated motor action. It is claimed by some that in the pons we have the spasm center on account of the fact that when it is subjected to severe stimulations the result is that extreme spasmodic cramp conditions follow.

The crura cerebri consist mainly of motor and sensory fibres between the cerebellum and the cerebrum and also between the basal ganglia, the pons and the medulla. In connection with these crura each crus consists of three portions, an anterior and inferior part, above this a gray lamina of pigmented substance and behind these another layer of fibres forming the tegmentum. In connection with the first part we find an internal portion continuous with the anterior part of the internal capsule, the geniculate fasciculus and the pyramidal fasciculus together with an external part coming from the posterior portion of the internal capsule with fibres in connection with the corpora geniculata and the caudate and lenticular nuclei. In connection with the tegmentum we find, (1) an internal part in connection with which we find two nuclei of gray matter, and (2) an internal part consisting of fibres in connection with the optic thalamus and the medulla. The only thing that is definitely known as to the crural functions is that they represent a medium for impulses. Irritation of the crura produces painful sensations and the destruction of one of the crura produces circular movements on the part of the body, indicating that the crura are connected in some way with the maintenance of the steady vertical position of the body and the equilibrium of the body particularly in locomotion.

In connection with the cerebral ganglia we find intermediate parts of the brain including the corpora quadrigemina, the optic thalami and the corpora striata, all of these ganglia acting with the cerebral hemispheres. The corpora quadrigemina represent two pairs of rounded bodies behind the optic thalami above the Sylvian aqueduct and closely connected with the crura, the pons, the medulla and the spinal cord. In these bodies we find gray matter overlaid with a layer of white matter. In size they represent a very small proportion of the gray mass in the higher animals. The posterior bodies are united to the cerebellum by the superior crura cerebelli and also the crura cerebri by the protuberances on the sides of the crura called the corpora geniculata. The anterior and posterior bodies are related to the optic tracts and also the optic thalami. From this it is evident that the corpora quadrigemina are connected in some way with the sense of vision. If they are destroyed blindness results. If the whole of the brain except these bodies is removed in the case of an animal like the pigeon there is still the normal contraction of the iris. If one of these bodies is then removed mobility is destroyed in the iris and accommodation capacity is also destroyed. Hence these bodies are said to contain the center through which impressions traveling along the optic nerve are conveyed. We find fibres in the third cranial nerve that control the contraction of the pupil of the eye and also the cilium which regulates the variations of sight distance. This third nerve arises in the gray matter on the floor of the Sylvian aqueduct contiguous to the corpora quadrigemina. Hence it is said that there is here a center of reflex action in connection with the iris and the cilium. When the retina receives a light impression the optic nerve is stimulated and an impression is said to pass along the optic tract to these bodies. When an impression reaches this center it causes activity of the center

and the impressions may be sent out in one of two directions; upward to certain nerve cells in the gray matter of the hemispheres and as a result from the stimulation of these visual sensation may be produced; or the center in the corpora quadrigemina may act merely as a reflex center, transmitting impressions received from the optic tracts to the various muscles and so leading to certain movements. This latter condition is said to exist in a state of somnambulism in which there is evidently a sight of the position followed by the body although it does not exist in consciousness, What we know definitely is, that these bodies have something to do with the iris and cilium motivity, although this is supposed not to represent a primary function on account of the fact that they are found to be excessively developed in the brain of the lower form of animal life. These bodies are considered to be concerned chiefly in the consciousness of color and of light.

In the optic thalami we find bodies that represent ganglionic groups behind the corpora striata and ~~posterior~~ to the corpora quadrigemina. The internal surfaces are seen in connection with the third ventricle. the external being connected with other portions of the brain. Fibres from the crus cerebri are found in the under surface, the upper surface being overlaid with fibres that pass between the thalamus and the corpora striata, constituting the internal capsule. The fibres which come from the thalamus to the capsule pass to the surface of the cerebral hemispheres. In the substance of the thalamus we find cells whose relations are yet unknown. The functions of the thalami are very obscure, although they are generally regarded as centers of impulses which when received from the periphery are sent forward to the corpora striata or even higher up to the cerebral hemispheres. It is supposed that these movements of impulses represent unconscious and entirely reflex actions. When the sensory impressions from the optic thalami are transmitted to the corpora striata from which these impulses pass through the crura cerebri the cerebral ganglia become centers of reflex action. If however the impulses pass to the cerebral centers then we find the activity of the higher cerebral centers. It is difficult to specialize the functions of these bodies because of their remote condition removed from the field of observation and experiment. It is certain that injury to these bodies does not result in paralysis of motivity or loss of sensibility. The only loss that is observable is that of lack of coordination in connection with limb movements. The most commonly accepted theory of the functions of these thalami is that they represent centers of tactile sensations in connection with sensory impression conveyed to them from the surfaces of the body. This means that the corpora quadrigemina and the optic thalami would represent the centers of the senses of vision and of touch on the basis of space, by means of which sensations are localized in space. The close connection of these two regions would also seem to indicate the close relation of space perception from the standpoint of vision and touch. In apoplectic cases involving the thalami we find interference with sensory activity on the side of injury. This has lead to the conclusion that these thalami represent the higher ganglia through which all sensory impulses pass and in which they are co-ordinated prior to their passage into the cerebral hemispheres. Thus they are secondary intermediate centers between the sensory and the cerebral centers.

In connection with the corpora striata we find that they are situated anterior to the optic thalami visible in connection with the internal ventri-

cle. The larger part of these bodies is found imbedded in the white matter of the hemispheres the portion that is visible from the floor of the ventricle being called intraventricular. The fibres from the thalamus establish a posterior connection with the corpus striatum while the inferior portion is connected with the pyramidal part of the medulla through the internal capsule. In the corpus striatum we find a coordinating center in connection with the motor impressions. The corpus may be stimulated by impulses that pass directly to it from the optic thalamus but it may also be stimulated by impulses reaching it from the cerebral hemisphere. These corpora are certainly engaged in the transmission of impulses received from the cerebral cortex, some say also from the optic thalamus, to the muscles. If there is a blood clot in the left corpus striatum there is motor paralysis in connection with the right side of the body, the paralysis affecting the muscles according to the extent of the clot. If the two corpora are destroyed voluntary movement is destroyed although there is still the power of forward movement in connection with the extremities. If the nucleus of the intra-ventricular portion is destroyed unconsciousness results. A lesion in the corpus striatum thus produces paralysis, that is motor impressions originating in the voluntary senses on the surface of the hemispheres are no longer able to reach the muscles and arouse muscle activity as the motor tract decussates at the anterior pyramids. According to Magendie a lesion in connection with the corpora striata not only destroys the capacity of regulating voluntary movements but produces a tendency to move forward without any power to regulate or to stop these movements. From this it follows that the paralysis will be found on the side opposite to the lesion in connection with the corpus. A voluntary impulse passes from the cerebrum through the crus and pons Varolii on the same side to the medulla. From this the fibres decussate in the interior pyramidal region passing down the opposite side of the cord, some of the fibres passing down the same side and decussating further down the cord, completing the decussation of all the motor fibres before their passage from their anterior roots. The sensory impressions originating on the surface of the body pass to the cord through the posterior roots, going up along the same side of the cord for a distance that varies considerably, then entering the gray matter of the posterior horn, passing from cell to cell and then upwards along the posterior columns. They then enter the pons Varolli where the fibres decussate and enter the brain on the opposite side to that from which they originated. From this point decussation again takes place in the case of some fibres. When they reach the brain sensory impressions are received on the opposite side from that on which they enter.

The cerebellum has three crura, the superior, middle and inferior, which pass into the cerebellum at its front part. Internally there is a nucleus of gray matter, the corpus dentatum. Externally we find two layers, an outer with a few round cells and fibres and an inner with nucleated cells that are very closely connected. The cerebellum cannot be stimulated mechanically and its puncture does not produce pain but may result in the flexing of the head to one side. It is claimed that the irritation of the cerebellum by an induced current of electricity produces a peculiar motion of the eyes. If the middle crus is divided the animal will rotate around the long axis towards the divided side. By experimenting on a pigeon, dividing the cerebellum in parallel sections from the upper surface, there is found a progressive loss of locomotion. The first stage

represents the weakness of motion; this is followed when half of the cerebellum is removed by staggering; finally when it is all removed it is unable to support itself. None of the senses seem to be destroyed. This indicates that the cerebellum has to do with the coordinating power of motion independent of the sensations; the function of the cerebellum therefore is the securing of proper coordination of the movements that are associated with the body.

By the influence of the cerebellum the various muscles of the body concerned in body movements are enabled to act, each one at the proper time and to the proper extent. For example, in the action of winking the eye-lid motion is under the control of two muscles, the one elevating and other drawing down the lid. In connection with the lifting of an object in the hand there is a complicated action on the part of a number of muscles in the hand, the forearm, the arm and the shoulder. All of these muscles require to act in an automatic manner and the various muscles and groups of muscles require to act at the proper time. Most of these movements are purely unconscious although they were originally conscious actions. The body movements give rise to certain sensations, these sensations regulating the action that is necessary on the part of the muscles in order to the maintenance of the body equilibrium or to the muscular movements that are associated with locomotion. At first the action on the part of the body muscles involves a conscious process, the peripheral impulses passing to the centers along the nerves of sense originating in the skin, muscles and viscera. In connection with the special senses of sight and hearing we have impulses that have a great deal to do with body equilibrium and movement. Certain impulses originate in connection with the semicircular canals which are at the basis of equilibrium on the part of the body. The attitude of the head in reference to the body determines very largely the equilibrium of the body. The same thing is true of the sense of vision, as the blindfolding of an animal produces an unsteadiness in the body equilibrium, the precision of movement on the part of blind persons being an acquired habit, regulated largely by sensations that originate in connection with hearing and the tactile sense. Impulses originating peripherally pass to the centers and regulate coordination of movement, these peripheral impulses originating in connection with the sensitive nerves found in the skin, the muscles and the viscera; in connection with the auditory nerve fibres and in connection with the optic nerve fibres. It is supposed that all of these impressions are collected together in the cerebellum but how the impressions are coordinated is not known. The cerebellum is connected with a great many of the nerves that bear those sensory impulses. In connection with the restiform bodies sensory fibres pass to it from the spinal cord; there are nuclei in connectisn with the auditory nerve in the cerebellum and the corpora quadrigemina. When the cerebellum is directly excited there are found to follow certain motion of the eyeballs. In connection with cerebellar lesions it is found that sometimes blindness follows. Phrenology claims that the cerbellum is the seat of the sexual function but there seems to be no evidence in support of this idea in the case of lesions, in the crura cerebelli there are found to be characteristic movements, out of the ordinary locomotive movements of a rotatory character, the irritation of part of these crura intensifying these rotatory movements. In some cases where one portion of the cerebellar crus is injured or irritated it is found that a motion is produced towards the side of irritation or injury and in some cases lo-

comotive action is entirely destroyed while the animal performs circus like movements.

In the cerebral hemispheres we find the white matter consisting of ascending fibres, longitudinal fibres and transverse fibres. The inferior portion of the crura cerebri consists of bundles of longitudinal fibres springing from the anterior pyramid of the medulla, these fibres passing into the internal capsule, the fibres reaching the brain. The crusta as it ascends to the hemispheres is flattened down the fibres themselves spreading out in fan-shape. These fibres assume the form of a conical convex surface, the convex part being found directed upwards. Among the fibres localized we find sensory fibres from the posterior areas and the Goll columns, from the roots of the optic nerve and the olfactory lobes; the fibres of the pyramidal tracts pass through the internal capsule and the corona radiata terminating in the parietal lobe and the middle lobe of the cortex. There are also found fibres from the external portion of the optic thalamus which unite the internal capsule with the convolutions of the parietal and frontal lobes. There are also fibres from the exterior part of the caudate nucleus passing to the corona radiata with fibres from the superior part of the lenticular nucleus uniting with ascending fibres from the internal capsule. Other fibres are found to arise from the superior crus cerebelli, from the corpus callosum and in connection with the internal and external capsule reaching the cortex through the corona radiata. Among the longitudinal fibres are found those immediately beneath the cortical surface uniting with contiguous convolutions; the fibres of the fornicate convolution which originate in the anterior perforation encircling the corpus callosum and terminating in the same perforation, the off shoots entering the secondary convolutions. Among the transverse fibres we find the fibres of the corpus callosum passing from side to side and uniting the convolutions in connection with the hemispheres the anterior commisstual fibres pass backward towards the convolutions in the neighborhood of the Sylvian fissure. In connection with the cerebral lesions we find the following account of the fibre arrangement of intrest; fibrese that arise from the frontal convolutions are found in connection with the internal part of the cerebral crus and the anterior portion of the internal convolutions; fibres that pass from the lower portion of the ascending frontal convolutions are found at the bend of the internal capsule and of the crus; the fibres passing from the higher part of the ascending frontal convolutions are found in connection with the anterior portion of the posterior capsule and external portion of the peduncle; fibres arising from the lower part of the ascending parietal convolutions form the middle part of the posterior capsule and the inner portion of the external crural fasciculus; fibres arising from the posterior cerebral convolutions are found in connection with the posterior part of the posterior capsule and the external portion of the peduncle; fibres are found passing from the cortex cerebri towards the lenticular nucleus from which they pass into the peduncle while others pass from the optic thalamus to the cortex.

The gray matter of the hemispheres is connected with intelligence; hence mental disturbance is associated with a diseased condition of the gray matter. A sudden injury or compression or a fluid effusion resulting from inflammation produces unconsciousness. If the pressure is taken away, consciousness may be restored. If there is disease in connection with the white matter paralysis may result or convulsions may

be found without any loss of consciousness. Thus the gray matter on the surface of the cerebrum is associated with consciousness and with mental phenomena. This fact is the foundation fact in psychopathy, forming the basis of the modern remedial treatment of insanity. In connection with the cerebal hemispheres different methods have been followed in attempting to differentiate the 'convolutions. Some have attempted to observe the natural arrangement of the convolutions following the divisions marked out by the Rolandic and Sylvian fissures as well as by the points of connection that are established in connection with these fissures. Others have differentiated certain convolutions as for example, Broca's convolutions which represent one-third of the frontal region. Some experimenters have taken the brain and gradually sliced it into transverse sections so as to find out the relations of the different parts. If the gray matter of the hemispheres in a pigeon is gradually sliced off the animal becomes more and more stupefied and loses all consciousness, perception and volition being lost. Perfectly normal movements may be produced by stimulating the external surface. Such movements are purely reflex, are not accompanied by consciousness of the external stimuli and are not the result of voluntary effort. If the animal is fed it will live for months in this condition of stupor. A frog from which the cerebral lobes have been removed may be made to go through all its normal movements by a suitable external stimulation. Such movements in the frog never takes place spontaneously but only when stimulations are applied to the surface incicating that the actions are purely reflex. It will therefore appear that it is only through the cerebral hemispheres that the will is able to work and that the processes set up in the cells of the hemispheres as a result of the influence of the will cause impulses to travel along a nerve to the lower centers, from which afferent impulses pass out to the muscles. It may be taken as proved that the nervous processes and activities connected with volition, sensation and the other mental phenomena take place in and only in the nerve cells of the gray matter of the hemispheres. In early times it was supposed that all parts of the cerebral cortex had the same function. Broca discovered that the affection of speech as found in connection with paralytic conditions was associated with a lesion in the third frontal convolution. In such a case the person may know the object but may not be able to name it; he may be able to know the thing itself and also the word that would express it but he is unable to connect the two together so as to give definite expression to the idea. This was the earliest location of function in connection with the cerebral hemispheres. Later it was found by Schiff and others tnat electrical stimulation of the cortical surface did not affect or produce muscle movements from which it was concluded that the cortical substance was associated more particularly with the psychic phenomena. Hitzing in connection with the application of electricfty to the brain found that certaih movements took place in connection with the ciliary muscles. Ferrier then took up the subject using instead of the constant current an induced current. His experiments were carried on in connection with the monkey applying by analogy the motor areas found in the monkeys's brain to the brain of the human subject. These areas as found by him were limited to a certain part of the cortex. In connection with other portions of the brain stimulation did not produce any movement and hence he concluded that there was not only a motor area but also a psychic area. Experiments made by him over the surface of

the hemispheres led him to conclude that each hemisphere may be divided into three zones; (1) a posterior connected with sensory impulses; (2) a middle in which there are found a number of motor areas, the stimulation of which, at least in the case of the monkey, produces particular movements. This area is grouped around the fissure of Rolando; (3) an anterior zone containing inhibitory areas. Much discussion has arisen as to these areas. It has been found that by the removol of the gray matter there follows a weakening of the movements controlled by the area; after a short time these signs of weakening disappear. From this it was concluded that if one motor area is destroyed some other part may take up the function that was formerly discharged by the area that was destroyed. The motor areas in connection with the brain of the monkey were supposed to be localized; (1) in connection with the posterior part of the parietal lobe, connected with movements on the opposite hind leg. (2) At the upper part of the fissure of Rolando complicated movements associated with the fore and hind limbs on the opposite side and certain movements of the body connected with these. (3) In the ascending parietal convolutions an area associated with the movements of the hand and fingers on the opposite side of the body. (4) In connection with the posterior portion of the superior frontal convolution an area connected with the extension of the hand and arm of the opposite side. At the upper part of the ascending convolution an area connected with the flexion of the forearm on the opposite side. (6) In the median part of the ascending frontal convolution an area connected with the muscular movements of the mouth. (7) Beneath this in connection with the same convolution an area was localized associated with the lip and nasal movements. (8) At the inferior part of the ascending frontal and the posterior part of the third frontal convolution an area in connection with mouth and tongue movement. (9) At the inferior part of the ascending parietal convolution an area connected with the lateral movements of the head. (10) In connection with the posterior parts of the superior and middle convolution a region connected with the opening of the eyes and the motions of the eyes and of the head towards the opposite side of the body. (11) In connection with the angular convolution and the supramarginal lobule a region associated with various movements of the eyes and the contraction of the pupils. (12) In connection with the inframarginal lobule a center associated with the ears, localized as the center of hearing. Goltz experimented in connection with the removal of the gray matter by washing with a jet of water so as to prevent hemmorrhage. He found that there is a power of recovery from the removal of a certain area, the paralysis being due to the injury exciting the inhibition of other centers. It is suggested that definite movements do not depend solely upon a definite area, that they may depend upon two or more areas so that if one area is destroyed the function may be performed by another. According to Goltz paralysis is associated with an injury that produces an inhibition in connection with the centers that are below. Horsley and Schafer find that the tactile sensations are associated with the fornicate convolution.

It seems to be definitely established that different parts of the hemispheres have different functions so that definite areas are connected with the action of certain muscles or groups of muscles. It is possible that each muscles may not be associated with a single area but this does not destroy the work of localization that has already been accomplished. In proof of this fact we find that tumors pressing on a particular part of the

hemispheres are associated with paralysis of the special muscles, the successful removal of these tumors being followed by the disappearance of the paralysis. What is referred to as an aphasic condition due to a lesion or imperfect nutrition of the inferior frontal convolution of the left side is another proof of localization of function. Localization has taken place in connection with the following areas: (1) For the head and neck in the posterior part of the first frontal convolution. (2) For the facial muscles in the posterior part of the second frontal convolution. (3) For the articulatary movements in connection with the upper portion of the third left front convolution. (4) In connection with the arm at the middle of the ascending convolution. (5) In connection with the arm in the upper portion of the ascending convolution close to the Rolandic fissure. (6) In connection with the eyes the posterior parts of the first and second frontal convolutions. (7) For the body muscles in connection with the convolution of the corpus callosum and the marginal convolution. The visual center is localized in the occipital and the auditory center in the temporo-sphenoidal lobes; general sensibility being associated with the occipital and the posterior parts of the parietal lobes. According to Horsley and Schæfer the areas cannot be definitely separated from each other as they overlap each other, for example, the area of the arm is found in connection with the upper parts of the ascending frontal and parietal convolutions; this region is associated with the muscles of the shoulder, of the foreram, of the wrist and of the fingers in the different parts of this region from the upper to the lower. The face area is said to take in the ascending parietal and frontal convolutions to the Sylvian fissure. This area represents the eye, the nose, the mouth in its upper part and the jaws, tongue and lips in its lower part. The region of the head is represented as being associated with the frontal lobe anterior to the arm region. The region of the leg is found in connection with the median cortical centers passing over the border and being associated with an area extending from the parieto-occipital fissure to the body region. The body area is confined almost entirely to the marginal convolution.

In the same way the sensory areas have been localized by Ferrier and others. The angular gyrus in connection with stimulation was found to be associated with movements of the eye in connection with reflex sensory stimulation. In connection with the destruction of the angular gyrus on one side, the eye on the opposite side became blind whereas if the two gyri were destroyed total blindness follows without any motor paralysis. Thus it was claimed that the regular gyrus represents the center of sight. In the same way the auditory area was localized in the superior temporo-sphenoidal convolution just below the fissure of Sylvius; the taste and smell areas at the extremities of the temporo sphenoidal lobe and the area of tactile sensation in the gyrus uncinatus and the hippocampal gyrus. Horsley and Schaefer locate the area of sensibility in the gyrus fornicatus on account of the fact that they find following injury to the region a condition of semi-anaesthesia. It may be generally accepted that thr posterior part of the brain is concerned prinipally in receiving sensory impulses whereas the motor areas concerned in the sending out of impulses are associated with the middle and lateral regions and the frontal or anterior lobes are concerned with psychological actions, including volition, cognition and intelligence. Thus the gray matter may be topographically divided into three great areas; (1) the anterior or frontal concerned in psychic phenomena; (2) the

motor area representing the middle region, and (3) the posterior region representing sensory impressions. The differentiation of the brain may be accepted as a working theory in order to aid in the localization of pathological conditions in connection with the psychic and the physiological. The areas have already been mapped out to a considerable extent in the field of surgery so that there exists a physiological foundation for the different localized brain areas.

According to Goltz even when a large part of the cortex is removed blindness does not result but there is an interference with the sight. According to Munk there may be blindness produced by the destruction of a large part of the occipital lobes. Munk claims that there may be physical and also psychic blindness, the latter including incapacity to understand the impressions that are made in connection with the sense of vision; according to him the cortical surface of the oscipital lobes forms the physical basis in the cerebrum for the transformation of the visual sensations into perceptions. In the same way he says that the other sensations of touch, smell, taste and feeling are transformed into perception in connection with other parts of the cortex. According to Munk we find in the same cortical region nerve cells which give rise to motor impulses in connection with particular muscles and also cells for the reception of sensory impulses originating in the same muscles, indicating that the motor and sensory region in the cortex are found in the same cortical areas. It is claimed by those who defend this theory that the larger and deeper cells represent the motor while the smaller surface cells represent the sensory function. In opposition to this it is claimed that by the destruction of one area paralyzing a set of of muscles the sensory function in connection with the same muscles is not necessarily interferred with. It is also claimed that by the destruction of a different cortical area sensibility may be destroyed, indicating that motor and sensory functions are discharged by different areas. As we have stated the posterior part of the brain is the sensory region, the middle and lateral portions being engaged in transmitting the motor impulses out from the brain.

In regard to the anterior portion of the brain it is found that the stimulation of the præfrontal area does not produce any motor action and the complete destruction of it does not seem to interfere either with motion or sensation. According to Ferrier the removal of the anterior frontal lobe does not produce any change from the physiological to pathological; in the case of the monkey, instinct and feeling as well as the sensibility remain normal. There is no interference with voluntary motion and there is almost no chamge that would indicate any important variation produced by the absence of this large portion of brain substance. Yet, Ferrier says that an important change is observable in the intelligent character of the monkeys. He claims that they pass into a condition of apathy and stupor, becoming listless and even unintelligent to a certain degree, although they have not lost the function of intelligence. It is on this basis that the brain is made and that the prefrontal area of the brain is associated with intelligence. According to this the frontal region of the gray matter on the surface of the brain represent intelligence and volition. According to Hughlings Jackson diseases or lesions affecting certain regions on the cortex of the hemispheres produces spasms, these spasmodic actions being limited to certain muscles so that he claims we have the basis of the localization of motor functions in connection with

the cerebral hemispheres. Impulses coming in from the afferent nerve reach the cortex cerebri, this pathway being fully developed in connection with the higher animals. In order that the impulse may have its effect it must pass from the central system and enter into part of the body that is subject to control so that the impulses have definite paths from the cortex to the different regions of muscular action in connection with the body. Early experiments were made by Fritsch and Hitzig in connection with the cortical surface in the brain of the dog by the use of the interrupted constant current in which they found that certain movements are directly associated with certain parts of the cerebral cortex. In the case of rabbits and dogs stimulation has been applied to the open surface of the cerebral hemispheres. If a weak current is applied for a few seconds slight movements of the muscles are noticeable, the contraction continuing for a short time after the withdrawal of the stimulation. If the current is increased in strength a large number of muscles respond by contracting, sometimes producing convulsive movements. Very soon the response ceases to be given indicating the loss of irritability. In connection with the cortical surface we find that the areas are associated with the pathways leading to the special organs of sense. The area represented by the organ of vision is one that can be definitely localized in connection with stimulation. Ferrier claims that by the stimulation of other sensory regions movements may be produced, these movements being supposed to represent the localization of sensory areas. When the rest of the area is stimulated certain movements follow, these responsive movements having been made the basis of the localization of the sensory centers. If such stimulation is applied to the posterior part of the visual region, the eye turns down and if stimulation is applied to the ventral parts of the visual region the eye turns upward, the movements taking place in the two eyes even although stimulation is applied only to the one side. In connection with the other sensory areas similar results are received, indicating, (1) the existence of cells whose stimulation produces certain muscular contractions; and (2) that these cells while capable of receiving impressions from the sensory organs are also capable of stimulation from the cell itself. This would seem to indicate that although the areas are particularly adapted to receive impulses in connection with the special organs of sense the areas are not exclusively sensory. By the application of electrical stimulation to the different regions of these sense areas localizations have been made in connection with different senses and also with the different sensations. The hemisphere surface may thus be divided up into areas of motion and sensation and into sub-areas corresponding with the different parts of the body, the arms, the head, the body, the legs, etc. These areas may be also distinctly separated from one another as centers in which we have a combination of cells controlling the different parts of the organs of the body. This is identified with the localization of the motor regions which control the various body movements. Within this same motor area we may also localize the characteristic kinds of movements, such as extension and flexion of the arms and legs. This division into centers may be carefully made by separating the small areas from each other by means of incisions, so as to seperate all other influences from contiguous areas. By making an incision parallel with the surface beneath the cortex it will be found that stimulation applied to the white surface beneath gives no response, indicating that the impulses arising from the stimulation pass from the cortical

portion into the substance, thus entering the nerve path along which the impulses pass. This seems in indicate that by stimulating the cortex the impulses that are associated with muscular movements pass through certain changes within the cells on the surface and are then passed to the fibres that lie beneath. If this portion of the cortex is removed and stimulation is applied to the hemisphere a similar result may be found, except that the response in the case of muscle contraction is less coordinated and continuous only while the stimulation lasts. Thus the stimulation of the cortex affects the cells, impulses being aroused which pass from the cells to the fibres beneath and thence along the nerve tract to the muscles. If a part of the cortex is removed from the motor region there is found degeneration in connection with the internal capsule and the callosum substance uniting the hemispheres, the degeneration taking place on the same side and also in the fibres that cross the callosum to the other side. This gives us the difference between the parts which cross and the part that is not crossed, representing the crossed and the direct pyramidal areas. The direct pyramidal tract disappears in the spinal cord entering by the anterior commissure. The direct pyramidal tract is said to terminate in the spinal cord in the cervical and lumbar expansions.

Sherrington observed that in the case of unilateral injury of the cortex there is a degeneration in the two crossed pyramidal tracts, the degeneration being greater at the point of the two enlargements on the same side as the lesion. This indicates that there is an increase locally in connection with the fibres running on this side. He inferred that the fibres of the pyramidal tract recross in the spinal cord, there being two groups of fibres, the one group crossing and the other not crossing so that the two groups of fibres are found on the two sides of the cord. If this is true then we have a basis for the capacity of each cerebral hemisphere to contro the body movements on both sides of the body. As this degeneration is continuous it seems also to indicate that the cortical cells have neura reaching into the cell regions of the spinal cord, even as far as the sacral region, the different neura extending to the cervical and lumbar enlargements of the cord. If the spinal cord is divided midway in the dorsal region and the leg area region and then stimulated by the stimulation of the divided cord, in the former case we find impulses and in the latter case no impulses, because in the former case stimulation is applied to nerves that are passing to the lumbar region, whereas in the latter case the neura form the arm cells end in the cells of the cord nearer to the brain than the divided part of the cord. According to this we have a simple arrangement in connection with the cortical cells and the cells of the spinal cord. According to this the cell neura in the cortex extend to the spinal cord regions that control the movements of the arms, legs, muscles, etc. These neura of the cortical cells are contained wholly inside the central nervous system carrying impulses along the cord for distribution in the different cord regions, representing the combination of the axial cells. According to Sherrington there is a degeneration of some fibres as far down as the lumabr enlargement by an injury to the cortical arm area. In this way we have the connection established between the cortical cells and the cord cells. Thus the cortical areas represent the areas of movement, the size of the area having no relation to the muscle movements that are controlled. In what way the two sets of cells, namely the cortical and the cord, are connected together we are not able to say.

The nerve fibres found in the pyramidal tracts do not justify us in concluding that there is one fibre for each cell in the cortical region. This is supposed to be explained by the branching processes that are associated with the pyramidal fibres, each pyramidal fibre being connected with a number of the efferent cells, these efferent cells being probably arranged in groups. In the human subject as well as in all the higher animals this localization of areas seems to be most complete, the localization being studied chiefly in connection with the monkeys. The chief localizations of these areas are found in connection with the two central convolutions of the brain, these areas passing beyond only along the great longitudinal fissure. In studying the cortical anatomy from the standpoint of the areas we find that the head and face areas are separated widely from each other, the arm area lying between them and the area for the body being found between the arm and the leg. The order of the areas from the anterior posteriorly is as follows: head, arm, body trunk, legs. It is impossible to establish any relation between the size of the areas and the muscles that are controlled from those areas. It is claimed that the movements become more complicated as we pass from the posterior anteriorly, the head movements representing the most anterior areas and physiologically representing the most complicated movements that are associated with the body. These areas are divided into sub-areas, for example, the arm area is found to be associated with the shoulder movements at the upper part and at the lower part with the movements of the fingers. The same sub-division of areas is found in connection with the face and leg regions. It would seem from this that in connection with, for example, the shoulder sub-area the neura from the cortical cells carry impulses downward towards the efferent cells in the spinal cord from which impulses are sent out along the anterior roots to the shoulder muscles. The same thing is true of the other areas. In connection with the localization of the areas in the different animals it is found that there is an increase in the degree of perfection with which the cells are grouped together into areas so that as we pass upwards to man the different areas become more definite.

In connection with pathological observations and some direct experiments made upon the human subject it is found that the chief seat of these areas is in connection with the two central convolutions. In connection with the human subject the cortical cells become elaborated in connection with the lower centers that are so largely increased in the spinal cord. It is said that the entire cortex is united in connection with the motor and sensory areas by means of the neura which carry impulses to the motor areas and pass the impulses away from these motor areas towards the cells in the spinal cord. The cortex according to Munk is divided into areas in which are found the terminals of the afferent nerves indicating the areas connected with the organs of sense as the sensory areas and also the muscles representing motor areas. In this way the whole of the cortex in which localized areas are found consists of cells and fibres carrying impulses to those cells, the cells undergoing certain changes resulting in the passage of impulses to other portions of the cortex and to the central nervous system. All the different parts of the cortex which have special functions originate when stimulated certain movements; in the case, however, of stimulation in connection with the sensory areas movements are aroused which produce contraction of the muscles that are associated with the external organs of sense, these rep-

resenting a very small part of the motor activity that is associated with the brain in connection with the skeletal muscles.

There is a control on the part of certain cell groups in the cortex exercised over the same cell groups in the axial system of the spinal cord, as for example, where movements of the eye follow not only stimulations of the eye area but also of the parts of the occipital region. If stimulation of the cortex cerebri produces a response simply on one side that response is found in the side opposite to the one stimulated unless in cases of the symmetrical action of muscles, as for example, in the case of the eyes the action taking place simultaneously. The impulses leaving the cortex pass along the pyramidal tracts to the cells of the spinal cord; in the case of the human subject there is a large number of fibres representing the active operation of the cortical region and its close connection with the spinal cord. It is found that in the case of dividing the spinal cord in the monkey and in the human subject the pyramidal fibre area is larger in the human subject than in the monkey, indicating that a larger number of fibres are found in connection with this pyramidal tract in man. It is from this region that disturbances arising from the removal of the brain in the human subject produce reactions upon the entire nervous system, the connection being so close that great disturbance is found to follow. Our knowledge of the arrangement of the cells in the cortex depends largely upon the results of direct stimulation, indicating the complexity that is associated with the attempt to localize the different pathways uniting the cortex centers with the lower centers. In regard to the sensory areas these have been localized chiefly in connection with brain anatomy and brain injuries, both congenital and accidental. The olfactory center is localized at the point of the temporal lobe in close connection with the hippocampal convolution. The auditory region is said to be localized in the first and second temporal convolutions as injury to these produces deafness and their destruction on the one side produces deafness on the opposite side. The visual center is associated in some way with the cuneate lobule as the injury of this region affects the sight. If there is a lesion in the visual region of one hemisphere there is a partial affection of the sight in both eyes. In the case of the visual and auditory regions if the areas are removed the stimulation of the sub-cortical substance does not give any response. Thus the central cells in connection with vision, audition and olfaction must be in the cortex and if the impulses associated with sensations do not pass to these cells they do not call for any response from the center. It is possible voluntarily to produce contraction of any muscle group under the influence of any stimulation. Hence although the impulses from the cortex control certain organs of the body the fibres of the cortex are so associated together that the stimulation of one region may result in the motor impulse passing to another region and from that region to the appropriate organ. Thus when impulses pass to the visual center in connection with the visual stimulation the nerve impulse may be transferred from the visual to the hand center, the transference taking place along the association fibres so that the result may be found in a hand movement. These association fibres connect any of the lateral areas on the same side throughout the central nervous system. From this it would seem that these association tracts represent the pathways of union between the areas in the cortex. Broca pointed out that when a lesion is found in the third fron-

tal convolution of the left hemisphere there is a loss of speech. Hence he localized the speech center in this part of the cortex, this center being called the Broca center. This does not involve the inaction of the muscles of speech, probably on account of the fact that in this area there are found no cells which are immediately connected with the nuclei that govern the muscles of speech. The corresponding portions in the right hemisphere seem to have nothing to do with the regulation of speech.

From what we have seen it would seem that the sensory impulses are distributed in different cells among the different areas, these impulses being sent from the sensory to the motor regions by means of neura connecting the two regions, the short tracts being found in the cortex and the larger tracts in the deeper surface. There seems to be no uniform relation between the connecting tracts in the different areas and there is not symmetry in this connection as between the two hemispheres. For example, the connection between the area of vision and the motor area representing the arm is established by more nerve elements than the connection between the area of taste and the motor area for the legs. It seems that in the case of a right handed person a lesion in the left hemisphere is more hurtful than one in the right hemisphere. The lesion in the left hemisphere seems to be more frequent and to have a greater effect. The connections with the sense organs, at least in the case of the eye, the ear and speech seem to be more perfect in connection with the left side than with the right side. This implies more perfect differentiation of the impulses in the left hemisphere, because these impulses can reach the motor region of the left with geater ease than the right. As yet there is little evidence that the reverse is true in the case of left handed persons. It is easy to see how it is possible in the case of development of the sense organs on the right side that the individual tends normally to be left-brained. In connection with the pyramidal tract it is found from the standpoint of evolution that it is not evenly developed on the two sides of the cord and this may form the basis of the uneven development in adult life in connection with the two sides of the brain. It has not yet been shown that the crossed pyramidal tract in the mature condition possesses this inequality. Yet it is found that injuries producing aphasic and apraxic conditions are found chiefly in the left hemisphere in connection with persons who are right handed. If one hemisphere is injured in the mature individual there follows a decrease or loss of function, although this may be temporary if the person is immature, in which case the other hemispheres seem to be capable of performing the function of the injured hemisphere. The nerve cells whose neuron is found in the pyramidal tract must in the case of the human subject be the medium of a large number of impulses. If this cell is injured then the capacity of receiving or giving out impulses is modified or destroyed resulting in the loss of function of the part controlled. If the sending out cell is injured or destroyed then the muscles that are subject to the motor impulses from this cell become paralyzed. The sending-out cell may continue normal while the pathways along which impulses pass in reaching the cell may be modified or destroyed; this is the condition that we find associated with aphasia, the discharging cell not receiving a stimulus sufficient to produce a response. When a lesion is found in connection with the region between the visual and the motor areas there may be a capacity to recognize an object and even to understand its use without the capacity for adaptation, for example, to use the hand in connection with the use of the

object. In this case there is a lesion somewhere in the pathway between the sensory and the motor tracts interfering with the transmission of impulses to the center of motivity.

It is well known that there is a great difference in the sensitiveness of the different senses in connection with different individuals, particularly in the discrimination of a minimum of observable difference. This power of discrimination is largely due to the educative processes of the central nervous system. It is partly due also to differences that are found in the sensory pathways. In the case of those whose thoughts take place in connection with pictures of vision as compared with those who think from the standpoint of audition, it is evident that in the former case the visual cells in the cortical centers are more distinctly developed whereas in the latter case the auditory cells are more distinctly developed. We find the same difference in the capacity of expression, this capacity covering not only expression in writing or speaking but also capacityof expression in connection with manual signs or acts. In either of these cases there is a particular development in connection with the relationsof certain sensory centers to the motor areas, for example, of the hand, of phonation. We can not trace out the anatomical relations although there is undoubtedly a sensory-motor combination more or less complete in the different individuals. It is evident from this that a lesion will affect individuals very differently. Hence we cannot eliminate the personal equation in connection with the brain, this personal equation depending upon the educative processes that have been associated with the central nervous system. The relation of certain areas, for example, the sense organs, is shown to be true by the fact that a complexity of impressions followed by their sensations is necessary in order to bring the areas into activity, the response being given in the case of one or more of these organs, Differences exist among individuals in the capacity of discernment especially in the case of minute differences even with the same sense organs. The minuteness of this capacity of discernment does not depend entirely upon training, the difference being found also in the cells and the fibres representing the pathway of impulses to and from those cells. The visual cells seem to be more acute on account of their more perfect development and organization. The same thing is true of the capacity for expression as between the power of speech and the power of handwriting. In connection with the cortex we find that although the longer tracts are those prepared by impulses in the passage from center to center the shorter tracts are often chosen as the pathway on account of certain cell combinations.

Investigation has not as yet localized areas in connection with the whole cortex, so that a large part of the cortex remains latent. This latent part of the cortex may represent areas that have not yet been localized or it may represent indifferent parts of the cortical centers, The center of speech is not properly speaking either a motor or sensory area and yet when it is injured there is an interference with vocalization. The center of speech is thus regarded as composed of cells which form a pathway to the area represented by the vocalization muscles. On this analogy the latent regions of the cortex are supposed to represent pathways in connection with which impulses pass or modifications take place in the passage of impulses to the true motor area of the brain. From an anatomical standpoint the latent areas do not possess large enough tract connection to allow of the impulses arising from them producing contractions

Hence the value of these latent portions remains as yet undiscovered. In connection with the frontal parts of the cortex we find established connection with the pons Varolii and the cerebellum. In connection with the removal of one of the frontal lobes in the case of the monkey it is found that there is very slight disadvantage, whereas in the case of the removal of the frontal lobes a serious interference is involved. When the single frontal lobe is removed there are slight sensory and motor disturbances together with a diminution of sensibility on the opposite side of the body and a partial paralysis. In the case of the removal of the other frontal lobe the same changes take place on the opposite side of the body together with the absence of concentration in connection with body movement, loss of feeling and most of the psychic functions, together with increased irritability. From this it has been concluded that the frontal lobes have an important function to discharge in connection with the entire central nervous system, representing as is supposed the seat of intelligent activity in connection with all the actions of the lower parts of the nervous mechanism.

In connection with the coordination of body movements some interesting studies have been made in connection with the lower animals. All movements are regulated in connection with the sense of equilibrium which involves the psychic element of appreciation of the body relations in space. By an interference with this sense of equilibrium the movements of the body cease to be coordinated. This sense of equilibrium depends upon sensations that are associated with touch and vision and also with the muscular sense. But none of these sensations may be said to definitely determine the body equilibrium because certain changes may take place in connection with the body that are not determined by any of these sensations. Our determination of the body position and relations depends therefore upon our consciousness of certain sensations that are associated with the body position independent of touch, sight and the muscular sense. These impulses give us undoubtedly our knowledge of the body relations to space and form the basis of coordinated body movements. In connection with some of the lower animals such as the pigeon when the horizontal semicircular canal is divided or injured in any way the movements of the head are noticed to be indeterminate. In the case of the division of one of the vertical canals the movement is upward and downward. If only one of the canals is injured the condition is transitory while in the case of injury to both canals it is either permanent or at least remains for a longer time. Associated with these movements of the head there is a lack of coordination in connection with the movements of the body. There is no interference with audition and even if an abnormal stimulation of the auditory nerve took place the results of the division would be transitory. The amount of loss of coordination is found to differ in different animals; as the movements become more complex and the coordination more perfect, the interference with the canals produces the greater effect. In connection with some of the mammals, for example, the frog, it is found that the division of one of the canals results in certain movements in connection with the head and the eyes depending upon the canal which is affected. This results in a lack of coordination in motion. If all the canals are divided effects are noticeable to a greater extent, the lack of coordination becoming very characteristic. If all the canals are divided the lack of coordination becomes permanent. The same result is said to be associated with the division of the eighth nerve

or the division of the vestibular portion of that nerve, even when there is no interference with the semi-circular canals. The three canals are found to be associated with three different planes in relation to one another, so that by turning the head there is a difference in the pressure in connection with the endolymph found in connection with the different canals. By the changes of the endolymph in relation to the ampullae certain impulses are said to be originated in connection with the cristae which send up impulses into the brain forming the basis of the coordination of body movements. It is found that by opening one of the canals and allowing the air to pass through a canula into the cavity in which the endolymph is found different movements result as the endolymph makes its way towards or is driven away from the ampulla. It seems to be proved that the ampullar cristæ represents the sense organs in connection with which certain impulses are originated depending upon the movements of the head which form the basis of the sense of equilibrium in connection with the coordination of the body movements. The only movement of the head that affects the three canals is the rotation of the head; the motion of the head backward or forward and even up and down does not produce the same effect in connection with the ampulla. There must be therefore some means of originating impulses in connection with the various movements of the head. How these movements take place it is not known and it is found that the division of the cochlear branch of the eighth nerve does not seem to affect the coordination of body movements. From this it is evident that the vestibular branch of the eighth nerve represents the impulses that form the basis of coordination in connection with the equilibrium of the body and also in connection with coordinated body movements. In connection with experiments on the brain or injuries that are found associated with the brain certain artificial movements are found, these movements being of a very large character in some cases and less marked in others. One of the common forms of these abnormal movements is found in connection with the rotation about the longitudinal body axis. This is found in connection with the division of one of the cerebral peduncles or one of the cerebellar peduncles or in connection with the division of the pons and injuries to the corpora qurdrigemina and the medulla. In other cases we find what are called circus movements the animal rotating around about a center, sometimes to one side and sometimes to the other side. This is often found particularly in connection with uni-lateral sections of the different parts of the brain. Sometimes we find what is called the clock hand motion in connection with injuries due to the posterior corpora quadrigemina. These movements may assume different forms and the movements may themselves be either coordinated or incoordinated. Sometimes the animal runs straight forward unless impeded by some obstacle as in the case of injuries to the corpora striata. In connection with these different forms of abnormal movement the animal is found to put into these movements all its characteristic activity. The movements are continued until exhanstion ensues, unless as we find in some cases the movement itself originates from the fact that certain voluntary impulses are not able to gain egress from the body on account of some impediment in connection with the central nervous system. In most cases, however, a simple obstruction of volitional impulses cannot explain the characteristic incoordinated movements. Although we cannot explain the cause of these movements they indicate complexity of the coordinating mechanism.

especially in connection with the different parts of the brain and the relations and interrelations of the different parts of the brain mechanisn. In connection with animals that have been deprived of the cerebral hemispheres it is found that the coordinating mechanism lies between the cerebral hemispheres and the medulla. The relations of this coordinating mechanism to the other parts of the brain is not well known. In connection with the frog, after the cerebellar hemispheres have been removed it is easy to distinguish the parts that are left. On the removal of the optic thalami visual impulses in connection with body movements are absent. On the removal of the optic lobes the power of equilibrium is lost so that in the frog the special coordinating power of equilibrium must be localized in connection with the optic lobe. In the case of a frog the cerebellum is very small and its removal cannot take place without injury to the parts lying beneath so that it is difficult to determine how much the cerebellum has to do with coordination. In regard to the other animals including the birds and mammals it is difficult to determine what parts of the brain are associated with coordination.

It is not easy to determine the pathways of sensory impulses and the sensation development that is associated with the brain. It is also difficult to functionalize the different parts of the brain in connection with the gray matter and the fibre tract. In connection with the cerebellum we find very intimate relations established with the rest of the nervous system. In connection with the inferior crus whose fibres terminate in the dentate nucleus we find an uncrossed connection with the spinal cord and the medulla; in connection with the cerebellar tract it is closely connected with the posterior roots of the spinal nerves. It has also established a connection with the cuneate and the gracilis nuclei on the same side as well as with the vestibular portion of the eighth nerve and possibly some of the other cranial nerves. In connection with the middle crus whose fibres are associated with the superficial gray matter connection is established between the cerebellum and the pons and also fibres that are associated with the frontal and occipital regions of the cortex with the pons. In this way each side of the cerebellum has close connections established by decussation with the opposite side of the cerebrum. In connection with the superior peduncle we have both a crossed and an uncrossed connection although this is an indirect connection representing a pathway of impulses from the cerebellum to the cerebrum. In connection with the removal of a part or the whole of the cerebellum it is found that different results follow as we find also in the case of stimulation by electricity of the cerebellar surface. If one half is removed the effects are limited to the same side of the body. The removal of the entire cerebellum does not produce any psychic interference and does not seem to result in any special interference with the cutaneous sensations. In connection with the removal of the cerebellum certain of the abnormal movements are found, as for example, rotation, around the longitudinal body axis. Associated with this there is an incoordination of movement that interferes with locomotive activity and even muscular spasms in some cases producing body curvature. This condition may pass away but there is left behind a lack of coordination which is found in muscle spasms, unsteadiness of movement and even an irregularity in muscle movements. From this it is concluded that the cerebellum is in some way associated with the coordination of muscle contraction. It is claimed by some that cerebellar impulses are associated with volitional impulses regulating in some way

the voluntary and normal coordinating impulses which are at the basis of the tonic condition of the muscles in normal contractions. This, however, has not been proved unless we take it that the unsteadiness of gait in the case of cerebellar interference represents the interference with this cerebellar function. It is claimed by some that cerebellar injury is not symmetrical. This, however, does not seem to establish anything definite in regard to the function or functions of the cerebellum. There seems to be such a close relation established between the cerebrum and cerebellum that the two would naturally seem to act in coordination in the discharge of their special functions of coordination.

In connection with the corpora quadrigemina we find complex bodies, the different parts of which differ from each other in the gray matter and the fibre connection. In the anterior pair there is some relation to the sense of vision. This visual function is possibly limited to a small part of the bodies, one part possibly being associated with the optic tract and another with the fibres in connection with the cortex. It is also possible that there is a part devoted to coordination of movement. By the stimulation of the superficial portion of the posterior pair, at least in connection with the monkey, there is produced vocalization. This may be associated with reflex action although it is claimed that it has some relation to the vocal function and also to the sense of hearing. In animals like the frog in which the cerebellum is found to be small the optic lobes are supposed to be associated with the coordination of movements. By dividing the optic lobe there is a loss of the power of equilibrium associated with lack of coordination of movements. The optic lobes are supposed to be associated in some way with coordination of movements. In the case of the mammals interference with or removal of the posterior corpora quadrigemina does not produce blindness although it may give rise to a loss of coordination this loss of coordination being temporary. In connection with the anterior pair there is coordination of vision and possibly also coordination in connection with the posterior pair associated with hearing.

The brain taken as a whole has certain splanchnic movements. Respiratory and vasomotor action are associated with the medulla and the corpus striatum is associated with the heat centers. In connection with the upper parts of the brain strong influences are brought to bear upon respiration, vasomotor action and cardiac action through the medulla. Voluntary action also has a bearing through the lower centers upon most of the organic functions, as for example, in the case of micturition and defæcation. In connection with these movements the brain action seems to be confined to the acceleration or inhibition of the spinal centers. These are not therefore to be found in connection with the cortical motor areas as real centers in connection with these organic functions. The emotions have a much stronger influence over these visceral functions than the will, as for example, in the case of the heart and the glands. The cortex is intimately connected with the emotions and on this account the cortex forms the medium through which emotion acts upon the visceral activity. In connection with experiments not very definite results have been obtained, for example, it has been found by stimulating the cortex in the case of a dog that certain bladder movements have resulted, this impulse passing to the cord through the medulla. Others claim that the stimulation of certain parts of the cortex produces salival flow, on the basis of which it is claimed by some that there is a salival area posterior to the Sylvian fis-

sure in the case of the dog. Similar results have been claimed in the case of the heart and vasomotor action by stimulation of certain parts of the cortex. These results however have not been applied to the higher animals and it is questioned by some whether such an application can be made.

In connection with the time that is occupied by cerebral actions as we have seen already a certain time is necessary and this time varies according to the amount of psychic action that is involved. Experiments have been made to test the velocity in connection with a stimulus and a signal that is given as soon as a flash of light is seen or a sound is heard. The interval which is found to intervene between the stimulation and the signal is called the reaction period which is claimed to consist of three diferent stages, (1) the afferent period during which the afferent impulses pass along the afferent paths to the central system; (2) the central period or the time occupied in the central nervous system; and (3) the time that is occupied in the passage of the efferent impulses along the the efferent nerves. In connection with the efferent period there is little variation, whereas, during the afferent period there is much complexity and considerable difficulty in estimating the length of time that is occupied. This makes it difficult to form any estimate of the central period. There is always the personal element to be taken account of as every individual does not observe with the same amount of precision or during the same period of time. In connection with the central period there is the complexity involved in connection with the psychological conditions. When the afferent impulses are originated by means of stimulation they pass to the central system, complex changes taking place both physical and psychical in connection with sensation, perception and volition. All of these elements would require to be analyzed in order to determine the reaction time. In this connection we require to take account of the voluntary action that is associated with the will. Here it is difficult to discriminate between purely voluntary and involuntary movements. In the case of the lower animals it is true there is an essential difference between the voluntary and involuntary actions, but this difference is not found so completely differentiated in connection with the higher animals. In the distinction therefore between the voluntary and the involuntary elements we must take account not only of coordination in connection with the muscle and nerve elements but also the kind of process that is associated with the origination of the impulses. It is very difficult to draw a distinction between the volitional element and the involuntary element from this standpoint and this of course depends very largely upon our view of the cerebral cortex. In connection with the cerebral cortex as we have seen there is to be distinguished the motor areas and the sensory areas and the connections established between these areas. Having differentiated the motor area from the sensory the question is, what is the particular part that is played by this motor area in connection with the movements that are associated with the different parts of the body. The experiments together with clinical observations point distinctly to the fact that here we have a center with intimate connections with the lower parts of the nervous mechanism, the association taking place through the fibres of the pyramidal tract. These fibres are determined to a large extent by the cells which form their starting point and they have been traced out as we have seen by the processes of degeneration. Hence whatever takes place in the motor area is executed in connection with efferent impulses sent along

the pyramidal tracts.

According to the experimental evidence the speech movements are associated in some way with the third frontal convolution. The movements of speech are particularly skilfull in their execution and involve the greatest adaptation on the part of a delicate mechanism. There is a series of events all of which are properly coordinated involved in the vocalization of a single word so that if any of the links in a chain of connection is broken the action itself may fail. The failure may take place in connection with muscles, nerve terminals, nerve fibres in the medulla or in the upper part of the brain so that injuries involving any of these may result in imperfect speech or in the destruction of speech. Injury for example associated with the medulla results in the imperfection of speech due to incoordination in connection with motor impulses. Aphasic conditions, for example, are produced by injuries in connection with the cortex, the aphasia being either complete or incomplete, so that we are not able to determine the exact localization of the cortical speech area from these cases. In the case of partial aphasia there is sometimes involved a psychic condition associated with volition or emotion. It is concluded from facts like these that the center of speech in the cortex can not be limited to a single area, the complexity of the coordination involving a number of areas in the cortex. This means that the articulation does not originate from any particular point in the cortex but rather that something is found to take place in connection with this speech area which results in the sending out of impulses along the pyramidal tract to the medulla, where a series of actions are asociated together by coordination in connection with articulation. In connection with aphasia a distinction is drawn between two possible cases, the one arising from the efferency that is associated with the motive element and the other with the afferency of the sensory element. Thus the aphasic condition may be due to imperfection of activity either on the motor or on the sensory side. In the case of those who are congenitally deaf we have an illustration of the latter condition. By the removal of what is called the motor area from the cortex there is not only a loss of movement but also an interference with sensation. For example, by removing the arm area, there is not only paralysis of the arm but also the absence of sensation in connection with the cutaneous surfaces of the arm. The same thing is true of all the different parts of the body, the loss of movement being associated with a loss of sensation. The sensory loss seems to be simultaneous with the motor loss. In connection with the stimulation of the cortex, particularly where this has been associated with consciousness it is found that there are sensations that correspond with the particular area subjected to stimulation. This is in line with the known fact that in cases of epilepsy the movements which are associated with the epileptic condition have preceding sensations of a peculiar kind, both the sensations and the movements having a definite connection with the cortex. It is found that the cortical region associated with the motor areas is associated not only with movements but also and particularly with the sensations that are found associated with the different parts of the body. Hence the sensory areas follow very definitely the motor areas in the brain cortex. The loss of movement that is associated with the extirpation of a definite motor area is partly due to the loss of the motor and partly due to the loss of the sensory elements. It is claimed by some that the motor loss is really secondary, the primary loss being associated

with the sensory area. It has been found that the pyramidal tract represents an efferent pathway and lesion in connection with its origin in the cortex produces a loss of efferency. The extirpation of a cortical area interferes with sensation. Hence the relations that are involved in the cortical area of the cerebrum represent not simple but very complex functions and the execution of even a simple voluntary action involves a complicated process. Even if it is taken for granted that the cortical cell in connection with the pyramidal tract is motor its motor action is largely determined by its intimate relation with the other parts of the nervous mechanism. The sensory connections with the motor areas are clearly brought out in connection with the stimulation of the cortex in the case of the dog when it is subjected to morphine. By the application of a stimulation reduced to its minimum there is found to be no motive action, whereas, if there is an increase of stimulus contraction takes place in connection with the muscles. For example, by stimulating with a minimum stimulus the areas representing the forearm and if this stimulus is applied to the area periodically no motor action is found, whereas, if the skin is very gently stimulated at the same time as the minimum stimulus is applied a result will be obtained in the form of a contraction. From these facts we may conclude that a voluntary movement represents a complex process, the motor area in connection with the efferent pyramidal tract representing only a small part of the mechanism. In the case of the removal of a motor area there is the destruction of the voluntary and reflex activity at least for a time. In the case of the removal of an area associated with motion there is a recovery more or less complete after some time although there is no renewal in connection with the area. This would seem to indicate that the voluntary action can find a pathway for its execution in connection with coordination in some other way. The word voluntary as representing the will has been applied in the general sense.

It is possible that an individual may be brought into a certain condition involving will under the influence of hypnosis in which certain movements are performed under the influence of the will of another. We cannot settle with our present knowledge of hypnotic action the action of the central nervous system in connection with hypnosis. For a long time it has been known that hypnosis is possible in the case of some animals. According to Kircher a fowl can be hypnotized by putting its beak to the ground in front of a chalk line. It is claimed that many animals are hypnotized by sudden action, for example, altering the position of the body. In this hypnotic condition attention is the first requisite and the second may be said to be absolute obedience to the particular stimulation. The form of the stimulation is not of primary significance. Normally in attention a particular individual is subject to a particular stimulus and not subject to others. In connection with hypnotism there is a cerebral preoccupation which involves the extreme limit of preattention. Hypnotism resembles sleep in some respects, as the person under hypnosis seems to be asleep. Bernheim claims, however, that in the most perfect hypnosis there is no evidence of the sleep condition. In the normal sleep condition there is a very slight difference in excitability, the most noticeable being susceptibility to what are called professional stimuli. In the case of hypnotism this excitability becomes very unequal, one form of stimulation having an effect while others are without effect. This is evident from the fact that the feeling depends upon the will of the hypnotist. This does not mean that other stimuli had no effect on the indivi-

dual during the hypnotic condition, because these stimuli do make an impression. It has been demonstrated that a person when hypnotized although unable at the time to see or feel particular things could after the removal of the hypnotic condition recall the objects seen or the sounds heard. Hypnotism claims that a person in the hypnotic state can be at one and the same time physiologically deaf and psychically not deaf to a particular sound. In the case of a person hypnotised the individual becomes purely automatic, the stimulus in the form of a suggestion producing in connection with the cerebral cortex an idea which is subject to the control of the hypnotist. This idea is purely subjective and imaginary. In connection with the hypnotized individual there is a characteristic condition of psychic credulity which represents the devolution towards a more primitive condition such as we find in infancy in which automatic action is more evident than in the normally developed individual in whom reflection has been cultivated by means of educative processes. The educative process is of itself a suggestion process acting in connection with the brain under the influence of predisposition and preoccupation, under the direction of hereditary suggestiveness. In the hypnotic condition this suggestiveness is exaggerated so that the credulity becomes extreme and there is the evidence of an unquestioning acquiescence in certain suggestions. We must take account of the fact that suggestion has a greater force in the case of certain individuals who have an exaggerated cerebral condition tending towards passiveness. Hypnosis represents one of the forms in which mind influences body. Many such examples may be found associated with mental attitudes as these have an effect upon body conditions, as for example, in the case of imaginary diseases where physiologically there is no foundation for such diseases in the body system.

The question arises as to the way in which voluntary impulses pass from the brain to the spinal cord. Normally voluntary movements are carried out by impulses conveyed along the pyramidal tract to the spinal cord. In connection with the dog the entire pyramidal tract decussates in connection with the pyramids and it is found that where the pyramidal tract is divided along the spinal cord there is a loss of voluntary motion associated with the same side of the body below the point of division. It has been found that by dividing the cord in one lateral half there is a loss of voluntary motion in the case of the parts of the body supplied beneath the point of division. In connection with the loss of voluntary motion there is also an interference with sensations and a possible interference with voluntary movements to a slight extent on the other side in connection with the crossed fibres. In the case of the intact nervous system voluntary motion takes place therefore from the cortex in connection with the impulses that pass down the pyramidal tract to the motor regions of the cord and pass out along the motor fibres. The pyramidal tracts are found to occupy in the human subject a much more prominent position than in the case of the dog and other lower animals so that it may be inferred that the pyramidal tract represents the pathway for voluntary impulses to the spinal cord and peripheral extremities. In connection with the pyramidal tract it is found that in the upper parts of the cord there is only a partial crossing in the human subject, a number of fibres going straight down and crossing in connection with the cervical and upper dorsal regions. Hence in the case of hemisection in the cervical region there would be an interference with voluntary movements on the one side and also a partial interference on the other side.

CENTERS IN CONNECTION WITH THE BRAIN.—As we have seen the cord represents the centers of reflex action but in the medulla we find also reflex centers, as for example, simple reflex centers that are associated with the closing of the eyelids. We find other centers which exercise a control over the lower centers in the cord as the main vaso-motor center, the centers connected with sweat secretion and the dilatation of the pupils of the eye as well as the center of combination in connection with the reflex movements of the body. There are also found in the medulla automatic centers. In the medulla the center function is dependent upon blood conditions in connection with the circulation of the blood and the exchange of gases. By the introduction of this interchange there may be produced an excitation of these centers resulting in paralysis due to hyper-stimulation. A similar stimulus may be exerted by an excessive increase of temperature. The centers do not act at the same time and they are not all subject to the same excitability. There are two centers at least in the medulla that are constantly active, this activity taking the form of rhythmic action, namely, the respiratory and vaso-motor centers. The cardio-inhibitory center in connection with the heart, at least in some animals, remains in a condition of non-excitability, while in other animals it is normally slightly stimulated during the inspiratory period of the respiratory cycle along with the respiratory center. The convulsive center remains quiescent normally, only an abnormal stimulus arousing it to activity. It is thus the characteristic of the medulla that in it we find a combination of centers which are at the basis of the ordinary animal functions of the body. (1) The most important of the reflex centers that are found associated with the medulla are connected with coordination of movement. The center that is associated with the closing of the eyelids is one, the afferent nerves being found in connection with the sensory branches of the fifth nerve which bear impulses to the medulla, from which center they are passed to the center that is associated with the facial nerve through whose branches the efferent impulses are carried. This center is supposed to be located towards the posterior portion of the pons Varolii. The reflex action of this center acts on both sides of the body but this may be controlled by voluntary action as in the case of the winking one eye. If there is a strong stimulation the muscles associated with the nose and cheek may also contract in connection with the eyelids as a means of protecting the eyes more perfectly. Inconnection with the center of sneezing we find the afferent path in the nasal branches of the trigeminal and olfactory nerves, the efferent nerve paths being found in connection with the expiratory muscles. The act of sneezing is an involuntary act, it may, however, be inhibited in connection with pressure upon the nasal nerve. We find the center for coughing slightly above the inspiratory center, the afferent nerve being found in connection with the vagi and the efferent nerves in connection with those of expiration and the closure of the glottis. The center of sucking has as its afferent nerves the sensory branches of the trigeminal and glosso-pharyngeal and the efferent in connection with the facial, the hypoglossal and the inferior maxillary branch of the trigeminal. The mastication center is the same and has the same nerves, the only difference being that the hypoglossal in connection with the tongue and the facial in connection with the buccal muscles are brought into play when the food is passed into the dental arch. We find the center of salival secretion in connection with the floor of the fourth ventrical. By stimulating the medulla there is produced a largely in-

creased salival flow, provided the chorda tympani and the glosso-pharyngeal are not divided. if the cervical sympathetic is destroyed secretion is destroyed. The center of deglutition is found in connection with the floor of the fourth ventrical, the afferent nerves being found in the branches of the trigeminal, the glosso-pharyngeal and the vagi, while the efferent paths are found in the motor fibres in connection with the pharyngeal plexus. If the glosso-pharyngeal is stimulated the process of deglution is inhibited. The result of this is that by stimulating the nerves in connection with the palate there is a contraction of the diaphragm that results in rendering the deglutition impossible. It is claimed by some that during the deglutition process there is always a weak stimulation of the respiratory center, so that at every attempt to swallow there is a diaphragm contraction. It is also claimed that there is an interference with the cardio-inhibitory center producing an increased activity on the part of the heart. The vomiting center is found in the medulla in connection with the terminal of certain branches of the vagi. The main center in connection with the dilatation of the pupils of the eye and the eyelids themselves is found in the medulla. The nerves are found in connection with the trigeminal and also in the lateral column of the spinal cord, passing to the cilio-spinal center, from which they pass out along the the two last cervical and first dorsal nerves into the cervical sympathetic. We find in the medulla a center of reflex action whose function seems to be to coordinate the action of the different centers in the spinal cord. In connection with the division of the medulla above the calamus scriptorius it has been found that the body movements are not interfered with while by division nearer to the calamus the reflex action of the body extremities is interfered with. This center is supposed to be located in the lowest part of the medulla. On the analogy of the lower animals like the frog it is claimed that the medulla is the general center in connection with locomotor movements, these locomotive movements being lost if the medulla is divided.

In the medulla we find the center of respiration. Respiration involves the coordination involuntarily of a large number of actions, the coordinated action being executed by the voluntary muscles. The respiration is automatic as it is continued in sleep and during unconsciousness and may be still continued if a certain part of the medulla is not interfered with. This coordination of impulses takes place in connection with the medullary respiratory center, the impulses being sent out along the nerves which supply the muscles of respiration. If the spinal cord is divided beneath the level of the fifth cervical intercostal respiration is destroyed; if the cord is divided just beneath the medulla diaphragm action is also destroyed because of cutting off the phrenic nerve impulses. but there is still continued the movements associated with the muscles supplied by the seventh and vagi nerves. The respiratory center is found in the medulla close to to the origin of the vagi on both sides of the median line close to the calamus scriptorius near the origin of the vagi and spinal accessory. The actions of this center we discussed in connection with respiration. Some claim that there is a center of inspiration in connection with the optic thalamus receiving its stimulus through the optic and auditory nerves, the stimulation passing through it along these nerves accelerating inspiratory action. Along with this there is claimed to be found an expiratory center in the anterior bodies of the corpora quadrigemina and another inspiratory center in the posterior bodies of the cor-

pora quadrigemina, these three centers being closely connected with the medullary centers. In the respiratory center we find impulses that are claimed to be derived from subsidiary cerebral respiratory centers, as for example, in connection with the corpus striatum and the optic thalamus. Other centers have been supposed to exist in connection with such conditions as apnœa and dyspnœa but these have not been as yet absloutely localized. The cardio-inhibitory centers are also found in connection with the medulla. By the stimulation of the vagi nerves there is a diminution of cardiac action; if the stimulation is strong the cardiac arrest takes place in diastole. The impulses that pass along the vagi are derived from the spinal accessory and are associaoed with the medullary center. The stimuli of the vagi are associated with the cardio-automatic rhythm and also with the contractile force of the heart particularly of the auricles of the heart. This center may be stimulated directly in connection with the medulla and also by the stimulation of afferent nerves. It is claimed by some that the center is normally in a condition of tonic stimulation, so that there is being sent out from this center continuously inhibitory impulses that keep the heart in a tonic inhibitory condition. Bernstein claims that this tonicity of impulse takes place reflexly in connection with the cervical and abdominal sympathetics. Stimulation of this center may take place directly in connection with the same stimuli as affect the center of respiration. By the sudden production of an anæmic condition of the medulla, if the vagi are not divided, there is produced a suspension and in some cases the destruction of the heart activity. The increase in the velocity of the blood produced either by the artificial introduction of vitiated air into the lungs or by the artificial destruction of respiration also stimulates the center. Similar stimulation may take place in connection with the excitation of the respiratory center or the increased blood pressure of the arteries and veins. Reflex stimulation may take place through the sensory nerves, as for example, the infra-orbital, the stimulation of the vagus and by the stimulation of the sensory nerve in connection with the abdomen or the intestines. Goltz by tapping on the intestines with his scalpel handle produced a stimulation sufficiently strong to produce a slowing of the heart action in the frog. By stimulating the vagus trunk at any point along its pathway away from the center the heart may be slowed or its action arrested altogether in diastole. We find a center probably associated with acceleration of the heart action in connection with the medulla. The nerve fibres originating in this center pass along the spinal cord, leaving the cord in connection with the upper dorsal nerves and entering the sympathetics. It is known that some of these nerves after leaving the spinal cord go through the first thoracic ganglion and the Vieussens circle uniting with the cardiac plexus. These accelerating fibres at least in the dog pass from the cord in connection with the anterior roots of the second and third thoracic nerves, possibly also the fourth and fifth, passing by the rami communicantes to the second thoracic and first thoracic ganglia, thence passing through the circle of Vieussens to the inferior cervical ganglia; thence they pass along the fibres in connection with the inferior cervical ganglion or those arising from one part of the annulus of Vieussens. At this point the fibres are non-medullated and as they are medullated before they pass into the sympathetic ganglia it is possible that they lose their medullation as they pass into the multipolar cells of these ganglia, continuing to pass from the ganglia to the heart as non-medullated fibres. By stimulating these nerve

fibres the heart action is increased and also its force so that it is claimed by some that the impulses emanating from the center in the medulla are both accelerator of action and augmentor of force. This center of acceleration is not in a normal condition of tonic excitation as the division of the accelerating nerve does not produce the slowing of the heart and the destruction of the medulla or of the cervical region of the spinal cord does not produce the slowing of heart action. In the case of the division of the spinal cord in the cervical region there must be a division previously of the splanchnic nerves so as to counteract the action in connection with the heart arising from the great fall in the blood pressure produced by the destruction of the cord.

One of the most important of the centers that we find in connection with the spinal cord is the vaso-motor center which regulates the motor activity of the unstriped muscles in the arterial system. It is found that this center extends from the upper part of the medullary floor towards the calamus scriptorius, the center lying on both sides of the median line, each half of the body having its own particular center. By stimulating this center there is a resulting contraction in the case of all the arteries producing an increase of blood pressure in the arteries and the dilatation of the veins. If this center is paralyzed the arteries become dilated producing a decided fall in the arterial blood pressure. The vaso-motor center is normally in a condition of continuous tonic stimulation. By dividing the brain from above downward in cross sections it is found that the reflex action is not affected until approaching near to the upper part of the medulla. By continuing the cross section into the medulla the reflex rise in blood pressure becomes less until it reaches the point where the effect on the blood pressure is destroyed. In connection with the stimulation of the center it is important to consider the quantity and quality of the gases associated with the blood as it flows through the brain. In an apnœic condition there is a slight stimulation of this center. In the normal condition of the blood the center is slightly stimulated. If the blood becomes excessively venous there is a strong stimulation of the center resulting in the strong contraction of the arteries of the body. The same result is found in connection with the ligature of the carotid and subclavian arteries producing an anæmic condition of the medulla. In the post-mortem condition the increased blood venosity stimulates strongly the vaso-motor center producing contr action of the arteries and thereby throwing the blood out of the arterial system. In addition to the main centers of vaso-motion in the medulla there are subordinate vaso-motor centers in the gray matter of the spinal cord. These subordinate centers act under the influence of the main center in the medulla; these may be stimulated directly by the blood in a dyspnœic condition. When the medulla is destroyed it is found that in the frog reflex action takes place in the arteries of the foot by the stimulation of the sensory nerves of the leg. There is found in the dog opposite to the third and sixth dorsal a spinal vaso-motor center which can be stimulated reflexly; a similar vaso-motor center has been found in the lower part of the spinal cord. The vaso-motor center in the medulla is also affected by cerebral action as is evident in connection with the psychic condition of fright. It is claimed by some that there is a center in the cerebral gray matter which upon stimulation produces a cooling of the opposite side of the body. In the medulla we find the center of convulsions at the point where it unites with the pons. This center may be stimulated by causing an exceeding-

ly venous blood condition as in the case of asphyxia by the sudden production of an anæmic condition of the medulla, as in the case of ligature of the carotid and subclavian. In these cases the center is stimulated by the interference with the normal respiratory interchange of gases resulting in convulsions. If these same changes take place gradually death may result from the depleted condition of the blood without any spasms. Another center is the sweat center which has subordinate centers in connection with the spinal cord. Although it cannot be very definitely localized it is claimed that it exists on the two sides of the brain and in some cases it may be found that there is not equal excitability on the two sides, the perspiration on one side being more profuse than the perspiration on the other side.

In connection with the cerebral hemispheres we have already seen the way in which the motor areas have been mapped out, these areas being first discovered by investigations in connection with the lower animals including the monkey. Clinical and pathological investigations have shown that similar areas may be found in connection with the human subject, those areas being found in connection with the region around the fissure of Rolando. These areas are localized in the central convolutions incluing the ascending frontal and parietal convolutions, the superior parietal lobule and the mesial surface of the hemispheres together with the paracentral lobule. In this area the upper third of the ascending frontal and parietal convolutions and the superior parietal represent the leg region, the middle third of the ascending parietal and frontal represent the arm region. The upper part of the lower third in connection with these same convolutions represents the face region; and the lowest part of the ascending frontal convolution the lip and tongue region. The head area is found in connection with part of the frontal lobe from the hemisphere margin to the area of the face anteriorly bounded by a non-localized portion of the frontal lobe. In connection with the sensory cortical centers much discussion has taken place as to whether these can be definitely localized or not. The results that have been reached on the basis of the investigations of Munk may be summarized as follows; the visual region is found in connection with the outer convex portion of the occipital lobe in the case of the brain of the monkey. It is probable that it also includes the mesial part of the occipital lobe including the cuneus. Schæfer claims that the visual area in the case of the monkey includes the entire occipital lobe and probably a part of the angular gyrus. According to Ferrier this center is associated with both the angular gyri and the occipital lobes called by him the occipito-angular region. The auditory area in the case of the dog according to Ferrier and Munk is found in the second primary convolution and in the monkey and the human subject in the temporo-sphenoidal gyrus. The extirpation of this entire region produces deafness in the opposite ear and the destruction of the middle portion psychic deafness. The olfactory center is supposed to be located in the hippocampal region at the lower extremity of the temporal lobe. The taste center according to Ferrier is localized beside the olfactory center. According to Ferrier the center for the tactile sensation , is found in the hippocampal region close to the point where the posterior cerebral artery is distributed.

The center of pain is supposed to be diffused over different regions of the brain. The sensory center in connection with the limbs is supposed to be localized in the hippocampal and fornicate convolutions. Munk be-

lieves that the surfaces of the cerebrum in connection with the motor centers act simultaneously as sensory centers in connection with the tactile and muscular sensations on the opposite side of the body. The thermal centers according to Landois are said to be associated with an area in which is found the motor centers of the muscles of the fore and hind limbs. The areas in connection with these limbs are separate, that of the fore-limb being anterior to the crucial sulcus and the posterior limb area being at the end of this same sulcus laterally. It was found that by the extirpation of theis region there was a temperature increase varying considerably, the rise in temperature continuing in different cases for a longer and shorter time. In connection with injuries to the fore brain there is not found to be any effect in connection with temperature. By puncturing the brain of the rabbit and forcing into it through the gray and white matter and into the corpus striatum a probe, there is found to be a sudden rise in temperature. While the injury of the gray matter on the cortical surface does not affect the temperature the puncture of the corpus striatum is found to produce a rise in temperature, at least after some time, this increase in temperature being produced more quickly as the puncture approaches near to the base of the brain. Hence it is claimed that the main center in connection with temperature is to be localized in connection with the corpus striatum.

SECTION VII. The Nervous System as a Whole.

The mass of the nervous system changes with age and certain other conditions, these modifications taking place in connection with the entire nervous system, having an important bearing upon the functions not only of the entire system but also of its parts. We take it for granted that the different parts of the nervous system possess a certain degree of functional activity, but there is a modification of this differentiated functional activity when all the different elements of the nervous system are combined together. Along with this general change there are found other changes in the relations of the different parts to each other, these variations producing the characteristics that are found associated with the different stages of life. The specialization of function is so entirely dependent upon form, especially in connection with the nutriment of the entire nervous system, that changes involve a complete change in nerve activity. Any variation that is found in the nutrition of the nervous system has a modifying effect upon the action and interaction of the different parts in their relations to one another. In the central nervous system the cells in themselves regarded as cell bodies represent the smaller proportion by weight, the neura and the other tissue substance of the system representing about 90 percent. In addition to the cells and the nerves we find vessels for the conveyance of blood and lymph and also the supporting tissues, these representing the mass usually estimated about equal to the mass of the cell bodies. The weight of the brain will include the weight of all of these different constituent parts. Sometimes the brain is weighed without the blood when it is cut up into sections. In other cases the brain is weighed with the blood. Sometimes the pia mater is also eliminated before weighing the brain, the pia averaging in weight from 40 to 60 grams according to Broca, the weight varying normally with the age. There is also a proportion of water varying from about 70 percent in the white matter to 80 percent in the gray matter.

The specifice gravity of the entire brain is estimated at 1,036 with a slight variation between the male and the female, there being a variation also in the different layers increasing from the outer surface inwards. The variation in weight depends therefore somewhat upon the changes in the different elements constituting the tissue. The complete brain weight will represent according to this the tissues themselves together with vessels, blood and lymph. Among individuals we find variations which depend entirely on the changes in the nerve cells, the larger the mass as a whole representing larger cells and consequently a larger amount of substance within the cells subject to chemical changes such as produce the changes in energy. There may be also a variation in the nerve fibres representing an enlargement or diminution of the pathway along which impulses may travel.

By the brain is meant that mass of the nervous system which is contained within the cranium. It is usually weighed after being drained of its fluids, the pia mater being allowed to remain in connection with the brain substance. According to anthropology there are said to be five different standards of the brain found among different individuals. The smallest is estimated from about 300 to 1,000 grams in the male and from 280 to 900 in the female; the small brain in the male is about 1,001, to 1,250 and in the female from 901 to 1,150 grams; the medium in the male is about 1,251 to 1,450 and in the female from 1,151 to 1,350; the large brain is in the male from 1,451 to 1,700 and in the female from 1,351 to 1,500; the largest brain is reckoned in the male from 1,701 to 1,925 and in the female from 1,501 to 1,745. The ordinary adult brain is represented by the medium size. In the different races we find great differences in the size of the brain, in the lower races of people the smaller brain being found. Even among the same races there are differences depending upon age, sex, stature and size. From 20 to 40 years of age represents the average adult size of the brain, the male brain being always heavier than that of the female, the variation being from about 125 to 185 grams at different ages and in different body sizes. Among those of the same sex and age those of larger stature generally have a larger brain, the weight increasing to about 40 years of age and thereafter gradually diminishing, the devolution changes being more marked after about 70 years of age. The same changes are not found in connection with the body weight, at least so constantly, perhaps chiefly because of the large proportion found in larger bodies. In general it may be said that heavier individuals have a larger nervous system. The change in weight found in connection with old age is probably due to the general decrease in nervous activity resulting in more or less of atrophy in connection with the nervous system as a whole. In the changes found in persons of larger stature the difference is probably due to the increase in the size of the cells and of the nerve elements. The same thing is probably true in regard to the differences between the sexes, the individual cell elements being found to be larger in the male. These differences do not depend upon functional activity as we find the same differences between the brains in the two sexes in the lower races, in which the intelligence and brain activity are at their lowest. The same thing is found in the case of the lower mammals. This seems to indicate that the difference is due to the size of the nerve elements rather than to an increase in the number of those elements. In the comparison between the brains of those occupying the lower strata of society and those of eminence in the social and intellectual world it is found that

on an average the latter have heavier brains and yet among those who have held positions of eminence in the social and intellectual scale there are found great variations in the weight of the brain, indicating that a large brain weight does not necessarily imply a high degree of mental capacity. The observations made by Manouvrier in connection with the brains of criminals and insane persons indicate that there are usually among these classes to be found brains of lesser size. There are also found, however, differences among the insane, depending upon the character of the insanity. In connection with the insane an important point of consideration is the disease with which the insanity is associated, where there are congested conditions the brain weight being greater and where there are destructive variations the weight is smaller.

In regard to the spinal cord very few observations have been made, the average weight in cases subjected to experiment giving a variation in the case of the cord without the nerve roots but including the pia mater of 24 to 34 grams. In the central nervous system we find normally a symmetry in the two halves of the system that is called bilateral. This, however is subject to exception, namely, that from a physiological standpoint the central nervous system is one sided, although from a structural standpoint it is bi-lateral. In nearly all the cases reported there is found to be a variation in weight between the right and left hemispheres. The same absence of symmetry is said to exist in other parts of the brain, for example, in the cerebellum, in which it is said that the molecular layer is thicker on the left than on the right side. These variations are explained by some in connection with the blood supply. The left carotid furnishes a more perfect supply of blood to the left hemisphere than the right carotid to the right hemisphere and this would provide a stronger nutritive influence in connection with the left hemisphere. This may account for the greater development on the left side, but as yet nothing has been formulated of a definite character by physiologists.

The brain and the spinal cord pass through many changes from the period of birth up to maturity, these growth changes representing interesting developments in connection with the central nervous system. In the cases reported by Vierordt the weight of the male brain after birth is 381 grams and of the female 384 grams; after the first year in all the reported cases the male brain exceeds that of the female brain in weight with an exception found by him in connection with 7 cases about the 14th year when the female brain represented a greater weight than that of the male, the female development at this stage being abnormal. In all Vierordt examined 839 cases. From these records, we find that at birth the brain weight is about one-fourth of its weight at maturity. It increases in weight very rapidly during the first year, the increase being gradual from the first to the eighth year after which it is very slow. This early growth may be associated in some way with the fact that the cranial bones are as yet not fully connected so that there is a freer capacity of brain growth. In some cases about the 15th year in the male and the 14th in the female there was found by Vierordt an abnormal development of the brain; if this development is too great it produces death or at least it is found associated with death at this age. These reported cases of Vierordt are all hospital cases and it must be remembered that these represent individuals not of the normal upper or middle classes but rather those of the lower classes; hence it has been inferred that conditions and circumstances associated with the life condition in society have much to

do with brain growth; this same point it is claimed applies to cases of senile brain atrophy. The point however to be noted in connection with the reported cases is the general development up to a certain point after which maturity continues for a lengthened period when decay and degeneration set in. According to the older physiologists the male child at birth has a heavier brain than the female. This however is contradicted by later investigations which indicate that the female brain is larger at birth or nearly equal to the male, the difference in weight arising later in connection with the brain development. The development of the brain differs from that of the body in that the former is more rapid, this brain development being usually almost complete before the 9th year. At this period the body has not attained more than one-third of the adult body size. This indicates that the brain and body development do not go side by side, for at birth the brain represents a little more than one eighth of the body weight, whereas, in the adult life the brain represents less than one fiftieth of the body weight. This change is due largely to the large muscle growth in connection with the adult life. From the standpoint of embryology it is pointed out that the increase in the number of nerve cells ceases after the third month of the intra-uterine life so that when new cells cease to be produced the enlargement must take place in connection with the increase in the size of the cells out of their embryonic form.

Side by side with the cell development we find also the development of the nerve fibres, these nerve fibres being either medullated or non-medullated. The cerebral cortex varies considerably the variation depending largely upon the size of the cerebral hemispheres. According to Yulpian the number of fibres found in the different layers of the cerebral hemisphere is at its maximum about 33 years of age, after this period a decrease taking place. Two kinds of fibres are found medullated and non-medullated. In both we find the isolation of the fibre in connection with the neurilemma; the non-medullated fibres are found in connection with the sympathetic system where the function is less differentiated and also to a certain extent in the central nervous system. It has been suggested that medullation represents a perfected condition and non-medullation an imperfect condition, the latter representing a condition which is found associated with part of the nervous system throughout the entire period of life. At birth the central nervous system possesses only imperfect medullation, the after development representing largely the completion of the medullary process. The medullated portion and the axis cylinder from above contain equal parts of the fibres. The fibres form as we said before 90 percent of the encephalon and about one-half of this would represent medullated fibres. It is estimated that in the entire central nervous system there are 3,000,000,000 of cells. In the central system about one-fourth of the substance represents the sustentacular tissue and blood vessels and the remainder nerve tissue proper. All of these cells in embryonic form can be accommodated in an area of three cubic centimeters which would represent about the size of the nervous system in the human fœtus at the end of the third month. In the case of the matured system it is estimated that there is an increase of 450 fold representing a volume which is within the normal limit of the encephalon and cord in the adult life. This involves an enlargement of the nerve elements amounting to 450 times the embryonic size. Thus we find the development of the central nervous system is due to a gradual enlarge-

ment of the cell elements found in the early embryonic stages, this enlargement taking place in the cell proper and in the formation of the neura together with the increase representing medullation, all of these changes following the development we have already considered. In the central nervous system the development becomes more complete as advance takes place in life and the system becames capable of greater activity as the impulses are increased. Thus the power of the nervous system becomes enlarged representing new functional development. The central nervous system in other words becomes more fully organized as the change takes place from immaturity to maturity. In embryonic condition the cells are isolated from one another. Out of their primitive location the neuroblasts migrate coming more closely together and forming as we have seen cell combinations. In the organization of the nervous system the chief changes that take place are those in the neura and dendrons. These are developed by extension, the neura developing outward towards the dendrons the dendrons also growing so that there is a constant approximation of the two towards each other. In the central system as well as in the sympathetic system medullation is not necessary to the functional activity; all the fibres that become medullated originate from non-medullated fibres so that medullation represents organization. In the afferent cells we find an increase in the neura and their branches presenting a larger surface for stimulation. In the central cells we find the increase of the neura and dendrons increasing the facility of receiving and sending out impulses. The efferent cells develop largely if not altogether by the development of dendrons. Thus the chief development of organization depends on the central cells which branch out in all possible ways. Imperfect development may be localized in any one or all of these different ways although deficient development usually takes place only in one way. The deficiency of one however usually involves the weakening of the rest.

In all this development the blood supply is an important consideration. The most delicate blood vessel connections are found associated with the cell bodies where they are most closely packed together in groups of cells. In this close relation of the blood vessels to the cell bodies in the gray matter we find the basis of the changes taking place in connection with these cells. The brain represents a very delicate organ and it is necessary that it should receive an abundant blood supply and that it should not be subjected to shocks from the pulsating vessels or pressure from the overfilied vessels. These are secured, (1) by the tortuous course of the arteries which carry the blood to the brain; (2) by the fact that the arteries are very delicately divided into branches before entering the brain substance, the division taking place in the pia mater; and (3) by the cerebro-spinal fluid as well as the continuity of the cranial cavity and the spinal canal. Hence if for any reason an unusual amount of blood enters the cranial vessels a corresponding amount of cerebro-spinal fluid goes down into the spinal canal and so the pressure on the cranial substance is prevented. There is no reflex variation in the blood vessels as there is no direct vasomotor nerve supply in connection with the vessels of the brain or the cord. Thus the blood varies very little as we find it circulating in the central nervous system. If the arterial pressure rises the blood flows more rapidly through the brain, but there is a corresponding increase in the venous blood flow. The amount of blood normally in the brain and spinal cord is small, not more than one 100th part of the entire

blood of the body. During mental activity there is an increased flow to the brain; when fatigue or exhaustion follows there is a diminished blood supply to the brain. Not only does the brain require a sufficient quantity of blood but it requires also blood of a sufficient quality. It is said that the thyroid gland has an important influence on the blood supply to the nervous system as the removal of the thyroid results in nervous weakening due to malnutrition. The use of thyroidin it is claimed has beneficial effects in the case of cretinous conditions involving the nervous system.

In regard to the cerebr-ospinal fluid its composition is not exactly known. Some specimens that have been examined as these have been found in connection with fractures of the base of the skull are normal whereas others in hydrocephalic conditions are abnormal. Most of the analyses have taken place in connection with the abnormal fluid. This cerebro-spinal fluid is a bright colorless fluid slightly alkaline in reaction with a specific gravity of 1,010. The larger part of the solid substance consists of salts, the amount of the salts depending upon the composition of the blood and the lymph. Proteids are very scanty in this fluid, the chief being a globulin identified by some as an albumose or peptone, albumin itself being normally absent. This fluid does not coagulate and does not contain any of the fibrin element. It also contains some sugar substance that is akin to dextrose. The composition of this fluid differs from that of the lymph and some claim that it is secreted in connection with the epithelium found in connection with the choroid plexus. There is no evidence, however, that such a secretory process does take place in connection with the choroid plexus, the most probable opinion being that if such a secretion does take place it is mixed with lymph. Whatever may be the color it seems to be furnished normally to the brain as one of the essential fluid substances. In connection with cases of fracture of the skull it is found to flow in considerable quantities and by the injection of saline substances into the blood the rate of the flow was found to be considerably increased. It has been found experimentally that to increase the arterial pressure does not produce any change in the flow of this fluid and this is taken by some as a proof that it is not ordinary lymph. The pressure that is found in connection with this fluid varies considerably, depending upon the vascular mechanism that is associated with the brain. This fluid finds its escape in connection with the elongations of the subarachnoidal space in connection with the nerve roots, these representing prolongations of the nerve lymph vessels; in the cranium such passages are found in connection with the cranial nerves more particularly the optic nerves. Some claim that the Pacchionian glands furnish a direct medium through which the fluid may pass into the blood in connection with the venous sinuses.

The rate at which this cerebro-spinal fluid escapes is of considerable importance. By sending an abnormal flow of blood into the brain there is a prevention of cranial compression by means of the removal of cerebro-spinal fluid from the cranium into the spinal canal and also by the passage of some of the fluid along the cranial nerves, so that in this way we have furnished a means of equilibrating the fluids in connection with brain circulation. In connection with the brain the vascular arrangements are of considerable importance. There is a special supply in connection with the right and left vertebral and internal carotids unification taking place in connection with the circle of Willis. Another important point in

connection with the supply of arterial blood to the brain is to be found in the fact that the three principal cerebral arteries have their distribution in connection with the cortex and underlying white matter, the deeper portion of the cerebrum being supplied in connection with smaller arteries that pass directly from the circle of Willis or branch from the beginning of the three cerebral arteries. No anastomosis takes place in connection with these two systems. There is a free anastomosis of the small arteries in the pia mater but there is very little anastomosis between the small arteries which pass from the pia mater into the deeper brain substance. This forms a reason why when these smaller arteries are obstructed there is an interference with the cortical nutrition of that part of the brain. In connection with the venous blood we find that the sinuses represent the chief channels for the passage of the venous blood, these sinuses representing receptacles that can easily be filled and as easily emptied, a free passage of the blood being possible without any interference. This has an important bearing upon the encasement of the brain substance within the cranium. When there is too much blood passed to the brain there must be provision made for it by the removal of some of the other fluids, otherwise a pressure upon the substance of the brain would result in danger to the brain itself. This accommodation is partially provided for by the removal of some of the cerebro-spinal fluid. In normal conditions, however, the sinuses are sufficient to regulate the blood pressure, representing as they do receptacles from which a large proportion of blood can be quickly discharged, this discharge being aided by the negative pressure found in connection with the veins at the neck during the inspiratory phases of respiration. Excessive pressure upon the brain substance in connection with the rupture of vessels and blood effusion resulting in brain compression, paralysis and even death. The blood supply to the brain seems to be small compared with the characteristic importance attached to the brain in connection with the body. In the case of a rabbit it is found that about one hundredth of the entire blood of the body is found in the brain; even in the human subject there is a very small blood supply relatively to the importance attached to the brain as an active organ. This would seem to indicate that the extent of brain metabolism is small and that its importance rests not so much in the amount of metabolic change as in the nature of it.

The mass of the brain is continually passing through changes in connection with the blood, these changes having a vital relation to the organic functions that are discharged by the body organs. At every heart beat there is found in connection with the cerebral substance a pulsation; at every respiration there is a double variation, during inspiration the lessening of pressure in the large neck veins producing a diminution and the opposite increase of pressure during expiration producing an enlargement of the brain substance. Other brain variations are found in connection with the movements of the body and the different parts of the body and also certain phases of activity determined by the conditions of wakefulness and sleep. In addition to this there is sometimes a vasomotion at the basis of the brain activity. By moving the head to the reclining position there is a tendency to accumulate blood within the cranium and in moving the head from this reclining position to the erect position there is a tendency to drive the blood out of the cranium. In both cases there is an interference with the cerebral equilibrium. When the brain substance is in its normal condition these changes have little if any

effect because of the compensatory capacity based upon the vaso-motor action in connection with the blood. In connection with the cerebral artery we find characteristic muscular walls and this forms a basis of the supposition that there are special vaso-motor fibres for the brain arteries. This supposition has not been carried out by means of experiments and the negative results seem to indicate the absence of such vaso-motor fibres. It is claimed by others that the blood flow in connection with the brain really depends upon the general vaso-motor mechanism having no vaso-motor fibres of its own. This seems to be almost as far as we can go in the discussion of this subject. The cerebral vessels according to this would be subject to the vaso-motor system, so that in case there is an increased blood pressure arising from vaso-constrictor action in connection with the abdominal organs there is of necessity an increased volume of blood passed to the brain and vice versa. This forms the basis of the automatic actions of the brain in connection with vaso-motion. This seems to be indicated by the fact that if the blood supply to the vaso-motor center in the medulla is lessened there is a stimulation aroused which produces vaso-constriction and results in an increase of the blood pressure resulting in the driving of blood into the brain. The blood flow in connection with the brain and consequently the brain changes may be subject to other modifications. Irritation applied to the motor areas of the cerebrum produces an outflow of venous blood without affecting materially the blood pressure. This forms the basis of the fact that there is claimed to be a special vaso-motor nervous mechanism in connection with the blood vessels of the brain. Thorertically the existence of this vaso-motor arrangement is more satisfactory in explanation of the facts that we find in connection with brain changes than that depending upon the general vaso-motor mechanism.

In connection with the brain it is important to consider the subject of sleep because it is claimed to be a particular phenomenon associated with the nervous system. In sleep we have the lessening of activity arising from diminished impulses passing through the central nervous system. This diminution may result from a voluntary reduction of the afferent impulses. Following this we find the nervous system gradually ceasing to give a response, representing either a condition of fatigue or the exercise of volition. The chief condition that favors sleep is the lessening of the passage of nerve impulses through the central nervous system. This may be accomplished by lessening the stimuli, by reducing those stimuli that are received to a minimum; it may also depend upon the excitability of the nervous system in connection with the condition of fatigue. Variations are found at different periods of life in connection with the active part played by the sensory and motor cells. During childhood the sensory impulses are not distributed over as large a sensory area and the impulses stored in the nerve cells are few as compared with those found in the adult condition. The same thing would be true of old age although in childhood there is a capacity of development which we do not find in old age, the nerve activity having become exhausted to a large extent. In the same way we find the supply of blood varying with age so that the amount of energy capable of being yielded varies with childhood, maturity and old age. Exercise induces a fatigued condition giving rise to afferent impressions which when conveyed to the center produce the sensations of fatigue. In connection with the body activity both of muscle and nerve there are certain

substances which when conveyed to the blood act the part of an inducent of sleep. Mosso has pointed out that if the blood of a dog fatigued by over-exertion is transfused into another dog that is not at all fatigued but that has been resting the resting dog will give signs of fatigue. It is inferred that there are certain metabolic products in the transfused blood that have brought about the change. The same thing is indicated by the difference in the sensations of fatigue depending on the form of fatigue and its inducing cause. We are able to distinguish between different degrees of fatigue the sensations that are associated with the different kinds of exercise differing among themselves. The preceding conditions of sleep may be summarized, (1) suspension of stimulation; (2) cessation of response in the case of the nerve centers; (3) a product of some kind in the blood, and (4) a decreased supply of blood to the brain These conditions can be produced artificially by the removal of the stimulation and by the use of certain anaesthetics. The loss of blood or the retarding of the circulation of the blood to the brain by pressure on the carotids induces unconsciousness analogous to sleep. These artificial conditions differ, however, from normal sleep in the effect that they have upon the central nervous system; in the former case there is more or less of a disturbance caused by the artificial means used to induce it, whereas, in the latter case normal cells act as a restorative of energy upon exhausted cells in the central nervous system. During sleep there is never a loss on the part of the central system or the power to react because if this were lost sleep would be permanent. Thus the central nervous system always retains even in sleep, during the continued vitality of the body, its power of responsiveness; if this power were lost it would be impossible to arouse anyone out of sleep. The person that is asleep is never removed from the influence of external stimulation. The plethysmograph has been used to demonstrate this fact. The arm is placed in the instrument and the person is allowed to go to sleep. It is found that after falling asleep a stimulation that is insufficient to arouse from sleep will produce variations in the volume of the arm due to the removal of blood from the arm. This must have increased the circulation of the blood in the brain without affecting the sleep in any way. This shows that during sleep the nervous system is capable of response without any consciousness of the reaction. Measurements have been made of the amount of stimulation necessary to awaken out of sleep. A ball was allowed to fall upon a plate with the object of producing a sound sufficient to effect the auditory impulses and thus by experiments it seems to be proved, that the first period of sleep is deep, whereas, the after periods are light, gradually becoming lighter until the period of awakening. This, however, gives no indication of the action of the central nervous system or of the changes taking place in connection with sleep as a restorative of exhausted energy. The loss of sleep has an important effect upon the system, producing irritation and resulting in death more rapidly than the deprivation of food. Experiments have been made on young dogs, the result of which seems to be that the loss of sleep for four days results in a fall of body heat and the loss of reflex action, accompanied by changes in the blood, hemorrhages in the brain and a shrivelled condition of the spinal cord followed on the fifth or sixth day by death.

During the decline of life we find certain changes involving alterations in the cells and throughout the entire nervous system. During the normal conditions of life there are certain metabolic changes taking place in

connection with the cells, these changes depending somewhat upon age. In youth the anabolic changes prevail, whereas, during old age the katabolic processes prevail. As we have seen the brain decreases in size, there is a shrinkage of the whole nervous system, involving both the cells and the nerve fibres. It is claimed by some that the fibres decrease in number especially the motor fibres. In the case of paralysis agitans the nerve cells become shrivelled, marked generally by degeneration extending to the fibres. Accompanying these changes we find an increase of the sustentacular tissues and an induration of the blood vessels accompanied by thickening of the vessel walls. Changes of this kind are more frequently found in the lumbar area of the spinal cord. This condition it is said represents an excessive degeneration such as is found in a lessened degree in the spinal cord of all aged persons. In regard to the brain the pathological examination has disclosed the fact that the chief changes in the brains of old people are found to be associated with the cerebellum where the cells are shrivelled and in some cases completely degenerated. Thus degeneration, destruction and shrinkage represent the condition of the brain and the spinal cord during old age, the dissolution taking place in such a way as to render the nervous system less active, less responsive and subject to erratic activity.

The physiologists have largely limited their investigations to the separate parts of the central nervous system without attempting to formulate any plan of action on the part of the system as a whole. This has produced in physiology a tendency to overestimate the importance of specialization of function, overlooking the fact that there is a solidarity and unity of action on the part of the entire system. It is probable that every active operation of the nervous system affects the whole system so that in this way there must be constant activity on the part of the nerve cells accompanied by continuous impulses entering and leaving those cells. This forms the basis of the continuity of conscious experience and is the necessary climax in our discussion of the nervous system and especially of the central nervous system. Behind consciousness, at least from a morphological standpoint, there lies the anatomical structure of the nervous system, but no one has as yet been able to solve the problem of their relations. The region of consciousness has been gradually moving upwards with the development of physiological theories until it has taken refuge in the only remaining region that is left over after the localization of the sensory and motor areas, namely, in the anterior portion of the gray matter of the cortex. Ancient philosophy did not limit the mind to brain. With the dawn of modern psychology the center of conscious, mental, emotional and volitional phenomena has been associated with the medulla and the lower parts of the brain and in more recent times has been localized in the frontal area of the cortex. Even if we could understand all the changes taking place in this region we should be unable to bridge the chasm between the purely subjective and objective, much less would we be able to resolve mental phenomena into their preceding causes. Philosophy is divided mainly into two schools, the one materializing the mental phenomena by ascribing them solely to physiological and physical causes, and the other idealizing them by calling them figurative names which give no explanation. By the combination of both of these ideas we have a fundamental physical and physiological basis for the ideal interpretation of these phenomena. This subject we leave to be discussed more fully in psychology.

SECTION VIII. The Peripheral Nervous System.

In the peripheral system as distinguished from the central nervous system, we find fibres originating from the central system which as distinguished from the central system are called peripheral. We have, (1) spinal nerves; (2) cranial nerves, and (3) the sympathetic nerves. (1) Of the spinal nerves originating from the spinal cord there are 31 pairs of nerves, each nerve having an anterior and a posterior root. Opposite each space between each pair of vertebræ a nerve passes out of the body. These nerves pass from the spinal canal by the intervertebral foramina. Hence these nerves are differentiated according to the vertebrae opposite to which they are found or between which they pass out. In the cervical region we find eight cervical nerves; in the dorsal regoin we find the dorsal nerves running between the ribs as the intercostal nerves. Passing down the spine we find the lumbar and sacral vertebrae the nerves corresponding to these originating in the lumbar enlargement and supplying the abdomen and by union forming the sciatic which provides peripheral innervation to the lower extremities. The lowest nerve roots form a bundle called the cauda equina. These nerves on passing from the spinal cord before becoming branched combine together in forming the different plexuses, distribution from which takes place in the different regions of the viscera, etc. The anterior branches in connection with the first four cervical nerves form the cervical plexus and the four lower cervical nerves the branchial plexus. The anterior branches of the dorsal nerves except the first supply the thoracic walls and abdomen, passing directly without forming a plexus. The anterior branches of the first four lumbar nerves form the lumbar plexus, the fifth, the branch of the fourth lumbar and the first sacral form the lumbo-sacral nerve and go to the sacral plexus. The first three sacral and a branch of the fourth sacral form the sacral plexus, the other branches of the fourth sacral being distributed in connection with the viscera in the pelvic region and the anus muscle; while the fifth sacral and the coccygeal find distribution in the coccyx. The spinal nerves are found to rise in connection with the posterior roots from the sulcus that lies between the posterior and lateral columns of the cord and also by an anterior root from the furrow that is found between the anterior and the lateral column. The posterior roots except in the case of the first cervical are larger than the anterior. Sometimes the roots on the opposite side of the cord are unsymmetrical. The posterior root is attached to the dorsal centers of the cord and is thicker than the anterior root attached to the ventral surface. The posterior root has a ganglion called the spinal ganglion, in this we find bioplar nerve cells. These two roots unite together to form a single trunk beyond the ganglion. The fibres of the anterior root are motor and those of the posterior root sensory. Bell found that by stimulating the anterior roots in an animal very soon after death muscle contraction followed; while the stimulation of the posterior roots produced no effect. By the irritation of the posterior roots, if the irritation is strong, pain may be produced. the result following the irritation of the peripheral-end of the anterior roots. This pain will continue if the main trunk is cut beyond the junction of the two roots, but it will cease if the posterior root is divided. This seems to indicate the presence of sensory fibres passing around from the posterior to the anterior roots, called loops or recurrent fibres, these fibres being traced out by the Wallerian degeneration. The afferent and

efferent fibres run along the trunk of the spinal nerve, dividing at the junction, the afferent fibres passing into the posterior roots and the efferent fibres into the anterior roots. If the anterior root is cut the muscles supplied with nervous connection cease to contract. If the peripheral end is stimulated the muscle will contract, but if the central end is stimulated there are no sensory impulses. If the posterior root is divided the muscles supplied with nervous connection continue to contract, sensibility being lost where the nerve distribution takes place. If the central end is stimulated sensory impulses are felt, but if the peripheral end be stimulated no effects are noticeable. According to Joseph, the spinal ganglion represents the trophic center for the greater number of the fibres, although individual fibres are found to pass through the ganglion without establishing connections in connection with the cells so that the trophic centers for these fibres are in connection with the spinal cord. In the anterior roots we find the efferent fibres which supply all the balance of the muscles in connection with the body and the upper and lower limbs. From the anterior roots we find motor fibres in connection with organs that possess the unstriped muscle fibres such as the bladder, the uterus and the ureter. The motor fibres for the muscles in connection with the blood vessels and the tonic nerve fibres in connection with the blood vessels as well as the accelerator fibres to the heart also pass from the anterior roots in connection with the sympathetics. We also find inhibitory fibres in connection with the blood vessels and inhibitory fibres to the heart which pass from the spinal cord to the vagi. There are also secretory fibres for the sweat glands which run through the sympathetics and the trophic fibres for the different tissues. In connection with the posterior roots we find the sensory nerves in connection with the skin, the tissues, with the exception of the face, the front and internal portions of the head. We also find the tactile nerves that are associated with the cutaneous surfaces of the body. In regard to the spinal ganglion there is no evidence that it can act independently as a reflex center, neither can it originate independent afferent impulses. It is intimately connected with the nutrition of the nerve fibres. If the posterior root is cut between the spinal cord and the ganglion the portion attached to the ganglion continues intact, degeneration taking place towards the spinal cord. If the anterior root is divided the spinal portion remains intact, while the peripheral portion degenerates towards the junction of the fibres with the trunk, the fibres degenerating in the trunk being efferent. If the posterior root is cut between the ganglion and the junction with the anterior root the part of the ganglion remains intact and also the root from the ganglion to the cord while nerve fibres in the trunk degenerate, these being afferent fibres. If the spina ganglion is completely extirpated the entire portion of the root degenerates and also the afferent fibres of the nerve trunk. The afferent fibres thus develop away from the spinal ganglion towards the periphery, in each case indicating the source of nutrition from the nerve cell. In the anterior roots we find efferent fibres without any ganglia and splanchnic fibres and also delicate ganglonated fibres whose ganglia are found at a distance from the central nervous system. The nerve fibres that go out along the posterior root pass through the spinal ganglia most of them entering the ganglion cells. In the case of the lower animals it is found that a nerve fibre when it enters a ganglion cell leaves it by one or more branches. In the cells of the posterior ganglion it is quite different because here the fibre passes through

the ganglion, giving off a branch at right angles to its pathway, this branch terminating in the nerve cells. This represents the T shaped junction, although it is difficult to appreciate the meaning of this anatomical fact. According to Raymond the nerve cell forms a shunting station. This is the only place in the nervous system so far as we know where such an arrangement is found. It is found that in the evolution of the nerve cell there is an enlargement on the side of the fibre. In connection with the function of this cell arrangement very little has been discovered. Raymond by the use of electricity tested the spinal ganglion and by stimulating a nerve root above the ganglion and connecting the lower part of the nerve with the galvanometer found that there was a variation in the part of the nerve beyond the ganglion, indicating that the impulse must have passed back through the ganglion. According to Exner this backward movement of the impulse does not indicate any loss of time in connection with the passage of the impulse. This did not seem to indicate what took place in connection with the branches, because later investigators have discovered that in connection with the peripheral ganglia there is a loss of time in the passage of the impulses. In connection with the pneumogastric, which in the rabbit has a ganglion very soon after it passes from the medulla, it has been found that by stimulating the central end of the vagus there is a change in the respiration. It is found that the time elasping between this stimulation and the result indicates the length of time necessary to pass the impulses to the center in the medulla and then down to the muscles of respiration. It is not known whether this loss of time indicates any particular action in connection with the ganglia. In connection with the ganglion it is found that the chief function discharged by the ganglion is that of nutrition of the fibres which are connected with the ganglion. In regard to the plexuses that are found associated with the different organs it is claimed by some that there is in these plexuses a coordination or rearrangement of the impulses in connection with muscular action. This has not been demonstrated so far, because it is not known that the plexuses exist for such a physiological purpose. Certainly there can be no coordination in the plexuses if the axis cylinders are not divided. The existence of the plexuses seems to consist in the fact that from an embryological standpoint the limb or organ consists of a portion that is divided from the primitive body which primarily may have given no evidence of existence. According to this the plexuses would represent the process of segmentation. The nerves grow out into the muscles or in connection with them so that as there is increased complexity in connection with the organ the segmented division takes place in the nerve corresponding with the segmental division in connection with the body and organ development. The plexuses therefore seem to represent the differentiation of organs and parts of the body.

(2) The cranial nerves. These nerves are 12 in number. They can be traced to nuclei in connection with the gray matter, these nuclei being found around the fourth ventricle. The cranial nerves in function are associated with the cortex on the opposite side and the cranial fibres can be traced in two stages from the cortex to the periphery, one from the cortex to the spinal bulb cell and another from the spinal bulb cell to the terminal in muscle or epithelium, so that these cranial nerves are like the spinal nerves, except that in the cranials the spinal cells are in the medulla. The deep origin of the cranials is found in connection with the medul-

la and pons under the floor of the fourth ventricle. In the case of the optic nerves we find close connection established with the basal ganglia through the optic tract in connection with the optic thalamus, the corpus geniculatum and the anterior corpora quadrigemina. The third and fourth have their nuclear origin in the corpora quadrigemina near the Sylvian aqueduct. The fifth has its nuclear origin on the floor of the fourth ventricle representing the motor nucleus. The sixth originates in the floor of the fourth ventricle and the seventh in the pons substance beneath the floor of the ventricle. The eighth has three nuclear origins in the lateral part of the floor of the fourth ventricle, the superficial giving rise to the cochlear branch and the deeper part to the vestibular branch. The ninth, tenth and eleventh nerves arise from the lateral portion of the gray matter in the medulla in the upper part of the spinal cord. The twelfth has its nucleus in the lower part of the medulla close to the median line.

The cranial nerves cannot be classified according to their uses, the most convenient arrangement being that of their number as they pass from the cranium. They have been classified as (1) nerves of special sense, 1st, 2nd and 8th with a gustatory branch of the 9th and a branch of the 7th to the lingual branch of the 5th. (2) Motor nerves, the third, fourth and sixth in connection with the muscles of the eye, a masticatory branch of the fifth, the seventh, eleventh and twelfth. (3) Sensory nerves, the ninth and tenth and the trifacial root of the fifth. This arrangement simply classifies the nerves from their roots, whereas, the branches become mixed. According to Dalton there are three pairs outside of the three of the special senses, these three pairs represent motor and sensory nerves. (1) Sensory, the fifth. Motor, third, fourth, sixth, and seventh and a motor root of the fifth; the distribution being found in the upper, middle and lower facial region. (2) Sensory, the ninth. Motor, the twelfth. The distribution being found in the regions of the tongue and the pharynx. (3) Sensory, the tenth; motor the eleventh, distributed in the passages of respiration and deglutition. The cranial nerves pass through the foramina in the base of the cranium. Of the cranial nerves three are exculsively associated with the special senses, the optic, auditory and olfactory. Two are common nerves and also connected with sensation, the fifth and eighth, the former having a motor fibre of its own and the latter receiving motor fibres from the vagi roots and the spinal accessory. All the rest are motor, the facial being associated with sensory fibres. Gaskell makes two divisions of the cranials; (1) four nerves with full segmented development, of which portions are lost because their function is lost, the third, fourth, sixth and motor parts of the fifth and seventh. (2) Five segmented nerves in which division has taken place to compensate for the lost parts of nerves; the ninth, tenth, eleventh and twelfth and the sensory portion of the fifth.

(a) The Olfactory Nerve or Nerve of Smell. This consists of the non-medullated nerve fibres which come off from the olfactory bulb, representing a lobe of the brain, originating by three roots from the frontal lobe, the anterior white commissure and the sphenoidal lobe. Branches are distributed to the upper two-thirds of the ethmoidal portion of the mucous menbrane of the nasal fossae. If this nerve is cut the loss of the power of smell results, although irritating odors can still be appreciated, as these stimulate the nerves of ordinary sensation which pass to the nasal fossae. It is purely sensory, carriyng impulses from the olfactory end organ in the nasal membrane. Physiologically stimulation takes

place in normal conditions by odorous bodies, although other stimuli may cause a sensation of smell. If the olfactory nerves are absent or divided the sense of smell does not exist. Each olfactory nerve is connected in both hemispheres. The olfactory nerve connection is indicated by means of its anatomical relation in connection with the olfactory tracts and the olfactory bulbs. In some animals the sense of smell is very acute and in these the olfactory bulbs and tracts are increased as compared with those found in man so that there is a correspondence between these tracts and bulbs and the development of the special sense.

(b) The Optic Nerve. It represents the prolongation of the optic tract and has three roots, the anterior arising from the posterior portion of the optic thalamus; the middle from the external corpus geniculatum and the anterior corpora quadrigemina; and the posterior from the internal corpus genticulatum and the posterior corpora quadrigemina. These roots constitute the optic tract, the two optic tracts uniting in the formation of the optic commissure. There is a decussatation of the optic fibres in the chiasm, about half of the fibres crossing to the optic nerve on the opposite side, with the result that the right tract supplies the right half of the two eyes and the left tract the left half of the two eyes. In this way the corresponding parts of each retina are closely connected with one hemisphere. It is purely a sensory nerve and represents the sense of vision. Peripherally it is represented by the retinal layer and cerebrally in the occipital region. Division of the optic nerve results in blindness of the corresponding eye and the stimulation of its central end causes light sensations. Normally the light must make impressions upon the optic nerve through the retina. The optic fibres pass over the median line at the optic chiasm, the decussation being as we have seen partial, each optic nerve giving a large number of fibres to the optic tract on the opposite side and a few to the optic tract on the same side. In the case of a human subject if one optic tract is destroyed we find unilateral hemiopia. This represents the loss of sight in the lateral halves of the two retinæ, the blinded part being divided from the seeing part by an ideal vertical line. Physiologically the stimulation of the optic nerve takes place only in connection with vibrations in connection with the retinal rods and cones. Other forms of stimulation when applied to the nerve produce reflexly pupil contraction in connection with the third nerve. By strong stimulation of the optic nerve the eyelids may be closed and a lachrymal secretion may follow. The optic nerve is connected with two centers, the general visual center and the center that is associated with the contraction of the pupil. Pathologically blindness may be associated with the activity of the iris and on the other hand the iris may lose its movements without a loss of vision. According to Gudden there are two kinds of fibres in connection with the optic nerve, delicate fibres whose center is found in the corpora quadrigemina on the opposite side and the large pupil contracting fibres which are associated with the external corpus geniculatum as a center. If the small fibres are divided blindness results, while if the large ones are divided there is a dilatation of the pupils. The optic nerve represents optic tracts uniting the cerebrum with the retinal layers in the eyeball. These fibres only carry impulses that originate in connection with rays of light, these impulses producing the light sensation in connection with the cerebrum. Magendie claims that the retina and the optic nerve is not sensitive to pain, the removal of the eyeball and the division of the optic nerve not being painful. In addition to the special

function of the optic nerve in transmitting the impression received by the retina to the center in the brain the optic nerves represent the nerve paths in connection with reflex contraction of the iris. These latter movements regulate the amount of light that is admitted to the eye and represent purely involuntary actions stimulated by impressions conveyed along the optic nerve to the corpora quadrigemina. This impulse is transmitted to the nucleus of the third nerve along which it passes as an afferent impulse.

(c) The oculo-motor nerve. It arises near the origin of the fourth nerve in the gray matter above the Sylvian aqueduct. Passing from the internal crural margin it terminates in two branches, the upper supplying the superior rectus and the levator palpebrae superioris and the lower supplying the rectus internus, the rectus inferior and also the inferior oblique, the circular fibres of the iris and the ciliary muscles. From the lower branch a nerve passes to the ciliary ganglion. On the opposite side this nerve is connected with the posterior portion of the parietal lobe. It is purely motor supplying all the muscles of the eyeball except the superior oblique, which is supplied by the fourth and the rectus externus supplied by the sixth. Hence when the third nerve is cut the eyeball is turned outward and downward, the upper eyelids drop, the pupil dilates and the power of accommodation is lost. If the peripheral end is stimulated these effects are counteracted. If the two branches are solid the vision is adapted to both eyes. When the muscles are paralyzed after division, there is double vision due to the elevation of the image on the paralyzed side. This nerve contains the motor fibres in connection with all the muscles except the external rectus and superior oblique, although the eyeball movements in coordination are not dependentupon voluntary action. We also find in this nerve the fibres which control the pupillary sphincter depending for excitation on impulses along the optic nerve. The voluntary fibres in connection with the ciliary muscle are found in this nerve representing the power of accomodation. It is claimed by some that the stimulation of this nerve causes a condition that is analogous to near-sightedness. The center in connection with the stimulation of the sphincter fibres of the pupil is found in the medulla. This represents a purely motor nerve, its stimulation being associated with convulsive movements of the muscles of the eyeball, if the stimulation takes place inside the cranium. If the nerve is divided paralysis follows in connection with the muscles to which the nerve is distributed, resulting in a condition of external strabismus, the external muscle and the internal being no longer associated in their anatagonistic action. There is also found an absence of mobility on the part of the eyeball on account of the absence of its rotatory motions. The muscles that are not paralyzed, namely, the external rectus and the superior oblique do not maintain their antagonistic action in relation to the paralyzed muscles. Accompanying this is the falling of the upper eyelid. In the normal action of the eye the upper eyelid only moves so that when the oculo-motor nerve is cut off there is no longer motion of the upper eyelid, the result being that the eyelid droops, covering over the upper part of the cornea and the greater part of the pupil. The third nerve is also associated with the contractile movement of the iris. The connection of the third nerve with the iris muscle is not direct, as it is established by means of the ophthalmic ganglion into which there is sent from it a motor fibre and from this ganglion the ciliary

nerves are given off to the iris. In the case of the division of the third nerve the movements of the iris are affected but it is claimed by some that the action takes place through the ganglion. In the case of experiments upon lower animals like the dog, the stimulation of the central end of the optic nerve produces pupil contraction in both eyes; this does not take place if the third nerve is divided. It has been found that when the the third nerve is divided the pupil is dilated and in the case of the eye that is operated on contraction takes place only imperfectly in connection with the rays of light. Complete paralysis has not taken place as movement is still possible in connection with the fifth nerve. The third nerve therefore seems to act reflexly as a result of the stimulation of light, but the action takes place only through the ophthalmic ganglion.

(d) The fourth, trochlearis or pathetic nerve. The nerve arises close to the root of the third. After crossing the nerve fibres appear on the upper crura cerebelli. It is a motor nerve and supplies the superior oblique muscle of the eye regulating eye rotation. When this nerve is paralyzed the head turns in a slanting position towards the paralyzed side. If the nerve is cut the eye turns upwards instead of rotating downward and outward and it also turns to one side. It represents a voluntary motor nerve although in the case of coordinated movements it is involuntary. In the case of paralysis of this nerve there is a partial loss of mobility in the eyeball outward and downward and also a slight squinting inward and upward with double vision. This nerve is distributed to a muscle which has no other nerve connection. By the use of electricity in connection with the stimulation of the nerve inside the cranium there is found to result contraction of the superior oblique muscle while the eyeball rotates on its long axis from without inward. Where paralysis of the nerve exists in the human subject the eyeball is incapable of rotation on the side that is affected, the images being placed obliquely, one over the other, with a resulting double vision. This nerve acts in conjunction with the third nerve in preserving the horizontal plane that is associated with the eyeball.

(e) The fifth or trigeminal nerve. This nerve arises by two roots, one root sensory originating in the gray matter of the medulla and another root motor arising from the nuclei of the gray matter; the motor root arising from the nucleus in the floor of the fourth ventricle and around the Sylvian aqueduct, the sensory root arising in the floor of the fourth ventricle and in the medulla and pons, these two corresponding with the posterior and anterior horns of the spinal cord. These roots arise from the side of the pons, the motor being smaller and the sensory larger having on it the Gasserian ganglion. The origins of the sensory root freely anastomose in connection with the motor nerves that arise in the medulla except the sixth. This forms the reason why there are so many reflex actions in connection with the fifth nerve. The sensory root divides into three, (1) the ophthalmic branch, which supplies sensory fibres to the eyebrow, upper eyelid, nasal fossae and forehead, the conjunctiva, nasal mucous membrane, the periosteum, frontal orbital and nasal regions, the infra-orbital muscles, etc. It also supplies the lachrymal mucous membrane influencing the lachrymal secretion. It has also connections with the otic ganglion and has a vaso-motor nerve to the iris and retina and sympathetic fibres to the iris. (2) The superior maxillary branch supplies sensory fibres to the lower eyelid from the nasal fossae, pharyngeal region, eustachian tube, upper teeth, palate, chest, etc.

It also supplies the nasal and palate glands and furnishes vasomotors to the blood vessels from the sympathetic. (3) The inferior maxillary branch supplies sensory fibres to the lower teeth, mucous membrane of the mouth and tongue, skin of the lower part of the face, chin, lips, gums, tympanum, etc. It represents the action of the nerve supply in connection with taste, audition and secretion. With this third branch there joins the motor root which supplies the muscles of mastication, the anterior belly of the digastric and the mylo-hyoid muscles. Thus the inferior maxillary is senso-motor. If the sensory root is cut sensation is lost in the external and mucous surfaces of the head, face, in the saliva glands and also the lachrymal glands and the teeth, while the tongue loses both sensation and taste. Mastication becomes difficult on account of the loss of sensibility. Accompanying this we find inflammation and ulceration of the cornea and finally complete destruction of the eyeball. If the nerve is cut on one side the jaw is pulled out to the one side that remains intact. The chief characteristic of the fifth nerve is its sensory character in connection with the cheeks and eyelids, the lips, the nose and the tongue which possess in a delicate degree sensibility. The nerve is very sensitive to mechanical stimulation and will respond to stimulation even when the spinal nerve seems to be insensitive. In connection with the division of this nerve we find the absenec of sensibility, for example, by dividing the infra-orbital branch, the sensation of touch may be entirely abolished in a portion of the face. By dividing the entire nerve before it leaves the cranium it is found that there is an entire loss of sensibility in connection with the skin and the mucous surfaces of the face as well as in the case of the eyelids. According to Longet when the fifth nerve is divided there is the entire absence of pain in connection with the most painful stimulation of the cord supplied by this nerve. In this nerve we find the seat of neuralgic conditions associated with the head and the face, as for example in the case of headache, either general or limited to a point of the head. In connection with toothache there is an irritation of the dental fibre of the fifth nerve. In the case of tic douloureux we find the most severe neuralgic conditions associated with one of the principal branches of the nerve in connection with the face. The lingual branch of the fifth nerve has its connection with the mucous membrane of the tongue, sensibility being very fully developed in connection with the anterior portion of the tongue and particularly at the tip of the tongue. If the fifth nerve is divided inside the cranium or if both of the lingual nerves are divided the tongue sensibility is entirely lost. This lingual sensibility has an important bearing upon the digestive function in connection with the appreciation of food flavor and also in assisting in the masticatory process which prepares the food for swallowing. In the lingual nerve branch we also find the sensibility of taste although this taste function cannot be very well understood on account of the difficulty in separating the different portions of the mouth in connection with experiments. It has been found that the margin and the upper surface of the tongue in the anterior portion can perceive taste sensations and according to Bernard the division of the lingual nerve abolishes the taste function. The muscular branches of the fifth nerve are all found in connection with the inferior maxillary branch being distributed to the temporal, masseter, pterygoid and mylo-hyoid muscles. These branches have a very close relation to the masticatory movement. The superior, middle and inferior areas of the face receive nerve branches from the fifth and the adjoining

parts of the face receive fibres from different sources so that there is a complexity of fibres in connection with the different regions. For example, in the case of the lower eyelid we find the anastomosis of fibres from the infraorbital and the ophthalmic branches. The skin of the nose also receives branches from the infraorbital and the ophthalmic branches. The most characteristic anastomosing branch is found in connection with the facial nerve to which we find sensory branches passing from the fifth. It is found impossible to destroy sensibility completely in any face region by the division of a single branch of the fifth, sensibility still continuing in connection with the anastomosing fibres from other branches of the nerve. In connection with the sense of smell we find that the nasal passages are supplied by the olfactory nerve as well as the nasal branches of the fifth in its distribution to the lower parts in connection with which we find general sensibility. We also find fibres from the sympathetic spheno-palatoid ganglion to the mucous membrane, these fibres being derived from the superior maxillary branch of the fifth. General sensibility in connection with the nasal passages is not destroyed by destroying the sense of smell, but if the fifth nerve is divided the general sensibility of the mucous membrane is abolished so that the power of smell is destroyed. In connection with the anterior portion of the eyeball we find sensory branches from the fifth nerve. In connection with the iris and cornea we find fibres from the sympathetic ganglion which derives its sensory root from the fifth nerve. In connection with the lingual branch of the fifth nerve we find the communication established in connection with the anterior part of the tongue in relation to general sensibility and the sensations of taste. The fifth nerve is supposed to be associated with the sense of hearing in connection with the fibres furnished to the external ear from the auriculo-temporal branch, its connection with the deeper portions of the organ of hearing being established in connection with the sympathetic otic ganglion to which fibres pass from the inferior maxillary division, a fibre passing backward to the plexus found in the interior membrane of the tympanum.

We find among the ganglia, (1) the ophthalmic ganglion. If destroyed the cornea becomes insensible and the pupil becomes dilated. The fifth supplies all the sensory fibres, the motor fibres coming from the third and the sympathetics. (2) The spheno-palatoid is found in connection with the superior maxliary branch. Its removal does not interfere with the smell or taste and no change takes place in the trophic influence exerted upon the fibres. The facial by the great superficial petrosal and by its union with the carotids supplies the motor fibres, the fifth supplying the sensory fibres, together with the sympathetics from the carotid plexus. (3) The otic ganglion is associated with the inferior maxillary. The motor fibres probably come from the facial through the small superficial petrosal and the sensory fibres from the glosso-pharyngeal and the sympathetics from the plexus of the middle meningeal artery. It is through this ganglion that the secretory fibres pass to the parotid gland. Its roots are found in connection with the inferior maxillary, the vasomotors from the middle meningeal plexus and the fibres from the tympanic branch of the glosso-pharyngeal. The facial nerve is connected with this ganglion by the chorda tympani. The branches of this ganglion are found in connection with the motor fibres for the tensor tympani and the tensor of the soft palate and also branches uniting the ganglion with the auriculo-tymporal from the sympathetic and glosso-pharyngeal.

(4) The submaxillary ganglion is associated by means of anterior and posterior roots with the lingual branch of the fifth nerve. Along the posterior root fibres pass from the chorda tympani and the inferior maxillary nerve. The sympathetics also send out fibres from the plexus in connection with the facial artery to the ganglion. Its roots are found in connection with the chorda tympani branches, furnishing secretory fibres and also vasomotor fibres to the submaxillary and sublingual glands. Its sympathetic root arises from the plexus in connection with the submental branch of the external maxillary artery in connection with which we find secretory and trophic fibres. Its sensory root arises from the lingual, some of the fibres passing through the ganglia and supplying the gland as well as its excretory ducts, a few of them uniting with the tympano-lingual branch of the tongue.

(f) The abducens or sixth nerve. It arises from the middle of the fourth ventricular floor passing between the medulla and pons. It supplies the external rectus muscle of the eyeball representing the voluntary nerve in connection with this muscle, although in the coordinated eyeball movements it is involuntary. If the nerve is cut the eye is dragged internally, resulting in a rotatory movement of the eye with an oblique pupil position. Six muscles supply the eyeball, the four recti muscles and the two oblique muscles, the upper eyelid being raised by the levator palpebrae superioris. There are seven pairs of nerves engaged in the optic work. The orbicularis palpebrarum closes the eyelid, the seventh supplies the nervous connections. Sometimes the origin of the facial is involved from the opposite side if this muscle is paralyzed. If the other muscles are paralyzed the facial trunk is affected. When the eyelids are first closed the upper lids falling over the eye there is a paralysis of the levator palpebrae superioris affecting the third nerve. The muscles supplied by the third nerve including all the eye muscles except the externus rectus and the superior oblique produce rotation of the eyeball internally and also upward. The superior oblique supplied by the fourth moves the eyeball down and outand the rectus externus supplied by the sixth moves the eyeball outward. In paralysis of the third the eyeball will be extended down and out with divergent strabismus. If the fourth is paralyzed the ball is directed up and internally with convergent strabismus just the same as in paralysis of the sixth. This strabismus involves double sight and always involves more or less movement of the head in the attempt to rectify the vision. This usually produces unsteadiness in locomotion. In connection with the experiments upon rabbits and horses this nerve is found to be exclusively a motor nerve, its stimulation at its origin producing contraction of the external rectus muscle of the eyeball. In this it differs from the trigeminal which always gives rise to increased sensibility.

(g) The facial nerve. The seventh nerve arises in the deep portion of the pons at the level of the sixth nucleus. The nerve fibres run backward and inward to the floor of the fourth ventricle, bending outward to pass over the sixth nucleus, bending forward to the lower margin of the pons. The seventh nerve represents the motor nerve to the facial muscles regulating the facial expression. The fibres that connect the nucleus and the cerebral cortex decussate in the pons so that a lesion above this produces paralysis of the face on the side opposite to the lesion, being confined to the muscles of the lower part of the face. In some cases the pyramidal tract and the facial nerve are injured, paralysis being found

in the face on the same side as the lesion. In connection with the chorda tympani it represents the pathway of vaso-dilator and secretory impulses. The fibres associated with taste in the chorda tympani spring from the glosso-pharyngeal. By the paralysis of one side the face ceases to be expressionable, the eyes are closed, the movements of the lips are interrupted and mastication is interfered with, the muscles being drawn towards the opposite side. When a lesion is found in connection with the seventh nerve in the fallopian aqueduct salivation and taste are interfered with. If the nerve is divided at its root the muscles of the face will be paralyzed, tho features being drawn towards the solid side. The side paralyzed becomes more prominent, the eyes being wide open and bulging. On one side the lips are paralyzed, although mastication is not suspended. There is an affection of the speech interfering with the pronunciation of certain letters and sounds, a lessening of salival secretion and an interference with deglutition, sometimes the hearing is also affected, although sensibility is not lost. This is the special nerve of facial expression. It is connected by a fibre with the auditory nerve. After passing into the fallopian aqueduct it enlarges into the ganglion geniculatum where connection is established with the otic and spheno-palatoid ganglia by the small and large superficial petrosals. At its origin the facial is not sensitive, but it becomes sensitive later, for example, in anastomosis with the vagi. The branches of the facial are found in connection with the large superficial petrosal, connecting branches passing from the geniculatum ganglion to the otic ganglion, a motor branch to the stapedius muscle; the chorda tympani, which arises from the facial before it passes out at the stylo-mastoid foramen and passes through the tympanic cavity emerging from the skull in the petro-tympanic fissure and uniting with the lingual nerve. When the facial passes out of its canal it furnishes motor fibres to the stylo-hyoid and the posterior belly of the digastric, together with the muscles of expression, the buccinator muscles and the muscles of the external ear. The facial branches of the seventh anastomose in connection with the trigeminal so that in this way sensory fibres pass to the muscles of expression. The sensory branches of the auricular pneumogastric branch pass into the peripheral portions of the facial, furnishing sensibility to the muscles of the ear. If the facial nerve is divided at the stylo-mastoid foramen it produces a painful sensation, this pain being increased by dividing the peripheral branches in connection with the face. By dividing the trigeminal nerve there is a complete destruction of tactile sensation even although the facial remains intact. In the case of paralysis of the orbicularis oculi, the eye on the side that is affected remains open on account of the fact that the muscles which open and close the eyes receive different nerve connections, the orbicularis oculi receiving fibres from the facial. When the facial nerve is paralyzed it is impossible completely to close the eyelid although the movements of the pupil and eyeball are not affected. When the facial nerve is divided we find the opposite effect to that found on the division of the fifth nerve, namely, paralysis of muscular action without any interference with sensibility. In the case of the division of the facial nerve the nostril on the affected side collapses and interferes with the entrance of air so that dyspnoea results. In the case of paralysis of the facial nerve the nostril movements are entirely destroyed. When the facial nerve is divided the nostril is in a collapsed condition during inspiration and during expiration it is partially open on account of the air that is emitted. When the facial nerve is divided the normal

movements of the lips are destroyed, the lips becoming inactive, the corner of the mouth falling downwards on account of paralysis of the orbicularis oris. In the case of the division of the facial nerve the ear on the side of the division ceases to move and hence there is an interference with the sense of hearing. Facial paralysis is commonly found in connection with a diseased condition of the facial nerve trunk, although it is usually limited to the one side resulting in a difference of expression on the two sides of the face. In the case of disease in the particular branches of the facial nerve only certain parts of the face may be affected, for example, paralysis may be found in the lips alone. If, however, the disease is in the nerve trunk inside the fallopian aqueduct there is a facial paralysis on the one side. In connection with this unilateral paralysis the muscles assume a collapsed appearance, the eye remains open, the eyelids cease to move and the lower lid falls down, the whole side of the face assuming an expressionless appearance. In addition to this there is the deviation of the mouth and the lower parts of the face on the one side towards the intact side on account of the absence of the antagonistic action of the muscles on the two sides of the face. Associated with this there is an interference with mastication and deglutition on account of the imperfect action of the orbicularis oris and also an interference with articulation on account of the fact that the lips cannot be brought together as in normal conditions. Where the paralysis is bilateral there is no longer a deviation towards one side although there is still the difficulty in articulation on account of the absence of contraction in the case of the orbicularis oris. In connection with the origin of this nerve there are decussating fibres which give a transverse communication in connection with its nucleus in the floor of the fourth ventricle and the opposite side. There is undoubtedly a crossed action in connection with the facial nerve as we find in cases of hemiplegia an accompanying facial paralysis. In cases where the cerebral injury is higher than the tuber annulare facial paralysis as well as the body paralysis is on the opposite side. In the case of a lesion below this there is usually facial paralysis on the same side and body paralysis on the opposite side. This indicates that the facial nerve has a crossed action above the nucleus affecting the opposite side and below the nucleus the same side. At its origin this nerve is distinctly motor but later it receives fibres from the trigeminal which make it sensory.

The chief branches are those derived from the inferior maxillary branch of the fifth which unite with the facial after it passes out of the stylo-mastoid foramen. In addition to this there is an anastomosis of the facial branches with the supra-and infra-orbital branches of the fifth nerve in connection with the anterior portion of the face. In its passage through the petrous part of the temporal bone the facial gives off some fibres which connect it with other nerves and with the sympathetic ganglia, the connections themselves being indistinctly understood. In connection with the geniculate ganglion there is found a delicate fibre which passes through the base of the skull and ends in the spheno-palatoid ganglion, this ganglion being associated also with the superior maxillary gland of the fifth which sends out branches to the mucous membrane in connection with the posterior nasal passages and the palate. This fibre connecting the facial with the spheno-palatoid ganglion represents the motor ganglion roots. Beneath this fibre there is another small fibre given off called the small superficial petrosal which establishes connection with the otic ganglion and the tympanic plexus so that fibres are sent out to

the mucous membrane of the tympanum and the tensor tympanic muscle. The stapedius branch of the facial passes to the stapedius muscle thus influencing the mechanism of audition, facial paralysis being sometimes accompanied by partial deafness. In connection with the descending part of the facial nerve we find two fibres which unite with the pneumogastric and the glosso-pharyngeal as motor fibres. The chorda tympani is given off from the facial before it passes out of the stylo-mastoid foramen, some of the fibres passing to the submaxillary ganglion and the gland while others pass on with the lingual nerve to the tongue. Physiologically the chorda tympani is associated with the circulatory and secretory processes of the submaxillary gland and also the tongue.

(h) The eighth nerve or the auditory nerve arises in the gray matter on the floor of the fourth ventrical and has connection established with the cerebellum, its function being auditory. It arises from two roots in the medulla, one going on either side of the restiform body. The auditory nucleus is on the floor of the fourth ventrical giving rise to two parts and an accessory in connection with the restiform body forming a nucleus for the dorsal root. The two roots are physiologically distinct, the dorsal root carrying the cochlear fibres and the ventrical root the fibres to the semicircular canals. The eighth nerve represents the function of audition and also equilibrium of the body. We find in the internal ear the peripheral end organ, the auditory part being in the cochlear and the equilibrium in the semicircular canals. By the division of the eighth nerve deafness and dizziness result, the stimulation of the central end producing subjective audition of sounds. There are thus two functions in with this auditory nerve, that of hearing and that of the equilibrium of the body in connection with ampullæ influence that are associated with the body movements. When the semicircular canals are injured or divided there is not an interference with hearing but there is an interference with equilibrium. It is very characteristic of this condition to find the pendulum movements of the head directed towards the plane of the divided canal. By the devision of the horizontal canal there is alternate movement towards the right and towards the left. By the division or injury of the vertecal canals there is a characteristic up and down movement of the head. If all the canals are destroyed it is impossible to maintain the erect posture, When the auditory nerve is divided there is an interference with this equilibrium of the body. In connection with the feeling of dizziness that is produced there is undoubtedly a false impression of the body relation to the environment and of body movements to the environment. Associated with these movements are also found characteristic movements of the head and of the eyeballs indicating that certain impulses are lost. If the Sylvian aqueduct is divided at the level of the auditory nucleus there is a disappearance of the normal movements of the head and eyeballs. It is claimed by some that a disturbance of equilibrium and also the giddy sensation may be produced by passing a constant current of electricity through the head so as to bring it into contact with tne semicircular canal. The auditory nerve is one of the nerves of special sense communicating impulses that are used by sound vibration to the cerebrum. It forms the exclusive nervous connection between the internal ear and the brain.

[i] In connection with the rest of the cranial nerves we find nerve distribution to the digestive and respiratory passages in connection with involuntary movements. The nuclei of origin are very close together. these nuclei being found the one after the other in connection with the

medulla. In connection with the glosso-pharyngeal and the vagus we find each possessing a separate ganglion and in connection with the spinal accessory which is a motor nerve we find a distinct nucleus with communicating branches to the glosso-pharyngeal and the pneumogastric. The glosso-pharyngeal or ninth nerve is in the main a sensory nerve, the sensory roots arising from the floor of the fourth ventricle in connection with the medulla. It has motor roots that arise in the gray matter of the medulla. It is distributed to the mucous membrane of the posterior part of tongue, the pillars of the fauces, the epiglottis and the tonsils and also to the tympanic membrane and the eustachian tubes. It is also distributed to the mucous membrane of the pharynx. It has motor fibres for the constrictors and the stylo-pharyngeus and sensory fibres for the mucous membrane of the back part of the tongue and the mouth. The ninth nerve was formerly supposed to consist of a single pair divided into three separate nerves, the glosso-pharyngeal, the pneumogastric and the spinal accessory. It represents the taste nerve for the anterior part of the tongue, the lateral portion of the soft palate and the fauces. As a sensory nerve impulses may be originated reflexly in connection with movements of the palate and of the pharynx. It represents also a motor nerve in connection with the stylo-pharyngeus aud the pharyngeus constrictors and according to some an inhibitory nerve in connection with deglutition. It is thus chiefly a sensory nerve. By stimulating the glosso-pharyngeal inside the cranium Longet claims that no muscular contraction can be produced, although Chauveau claims that he found contraction of the upper part of the pharynx. This result arises reflexly through the nerve connection with the medulla. It has been found that by stimulating the glosso-pharyngeal certain movements are found in connection with the face and the throat these movements being found after the division of the nerve and the stimulation of its central end. The functions of this nerve are two-fold, that associated with the sense of taste and that associated with deglutition. The taste sensation is found not only in connection with the anterior part of the tongue as supplied by the lingual branch of the fifth, but also at the posterior part of the tongue and in connection with the palate arches supplied by the glosso-pharyngeal. The sensibility of the posterior part of the tongue is not so delicate as that of the anterior part of the tongue; hence the sensibility of the ninth nerve is claimed to be inferior to that of the lingual branch of the fifth. In connection with the pharynx and the fauces the glosso-pharyngeal may be stimulated by impressions which arouse the muscles in connection with deglutition. This originates in the backward and upward movement of the base of the tongue in connection with which the masticated food passes through the arch of the fauces to the pharynx. After this the palato-glossal and palato-pharyngeal muscles close the entrance into the arch, the solt palate being extended over the upper part of the pharynx, keeping it from communicating with the posterior nares, while the constrictor muscles of the pharynx drive the food down to the oesophagus. These muscle movements take place even in unconsciousness so that the stimulation is aroused involuntarily, the impulse being carried along the glosso-pharyngeal to the medulla from which reflexly there passes a motor impulse. The glosso-pharyngeal after passing out of the jugluar foramen becomes a mixed nerve communicating with the facial and a branch of the pneumogastric, the latter consisting of motor fibres from the spinal accessory in its anastomosis with the vagus. It would seem that the motor fibres spring

from both the facial and the spinal accessory. The experiments of Bernard in connection with the division of the facial nerve in the fallopian aqueduct and also in the division of the spinal accessory on the two sides indicate that the deglutition process is simply hindered and not destroyed. Lower down the glosso-pharyngeal receives another branch from the facial which passes along with it to the stylo-glossal muscle and to the pillars of the fauces, another branch from the spinal accessory assisting in the formation of the pharyngeal plexus and furnishing the fibres to the upper pharyngeal constrictors. The deglutition process is stimulated through the impulses that pass along the glosso-pharyngeal while deglutition itself takes place in connection with reflex action through motor connection with different nerves.

(k) The vagus or pneumogastric arises in the medulla, the deep origin being in the gray matter close to the floor of the fourth ventricle. Most of the fibres pass through one of the two ganglia, the upper and the lower; some of the lower fibres passing without entering either of the ganglia. Between the ganglia there is a junction of the vagus and the internal spinal accessory, which is included within the vagus, forming the motor portion of the vagus. The motor fibres arise chiefly from the accessory and the sensory from the vagus. There is also a junction of the vagus with the sympathetic, the hypoglossal and the glosso-pharyngeal. The sensory nerve in connection with the mucous membrane of the larynx is the superior laryngeal branch. The vagus is distributed to the larynx, œsophagus, stomach, intestines, lungs, heart and liver. Its actions and relations are very complicated. The sensory fibres supply the mucous membrane of the larynx and other respiratories, the heart, the base of the the tongue, the œsophagus in connection with the œsophageal plexus, the stomach in connection withe gastric plexus and the duodenum. The muscles supplied by it are sensory, the mucous membrane of the bile duct and the posterior part of the auditory canal. The motor fibres representing the pharyngeal branches forming the pharyngeal plexus control the palati muscles, the pharyngeal constrictors and the œsophagus. The arytenoid and crico-thyroid muscles are supplied by the superior pharyngeal, all the other pharyngeal muscles being supplied by the inferior laryngeal. The pulmonary branches in connection with the pulmonaryplexus furnish sensory fibres for the the bronchi and motor fibres to the bronchi muscle and fibres that modify respiratory action. The vagus also furnishes the broncho-dilator and constrictor fibres. The vagus also has cardio-inhibitory fibres to the heart and the depressor fibres from the heart. The depressor nerve from the heart is found either in the vagus or its superior laryngeal branch. It also furnishes nerve connection to the liver in connection with the formation and secretion of glycogen and furnishes the secretory fibres to the stomach glands. Some claim that it also supplies the secretory fibres in connection with the kidneys. The vagus fibres are mainly afferent from the gastro-intestinal tract, the heart, the lungs and the larynx. The accessory nerve is chiefly efferent sending out motor fibres to the levator palati, larynx and œsophagus, inhibitory fibres to the heart and motor fibres to the bronchi, stomach and intestines. If the vagi are divided high up in the neck heart action is increased, deglutition is hindered, the laryngeal muscles are paralyzed and the lungs become œdematous. If the central end is stimulated respiration is increased, the heart is slowed and the blood pressure falls; if the per-

ipheral end is stimulated the heart is stopped, and the larynx, œsophagus, bronchi and stomach become contracted. The vagus is thus distributed to the passages in connection with which food and air pass into the body and it also establishes connection with the sympathetic and in connection with it with the heart. At its origin the pneumogastric seems to be purely sensory. If the nerve roots are stimulated separate from the medulla no result is found but if the nerve trunk is stimulated lower down muscular contraction results. At this point motor fibres have been added from the spinal accessory, the facial, the hypoglossal and the first two cervical nerves. Its sensibility is most characteristic and this is possibly due to the fact that it is so closely related to the functional activity of the most important vital organs. One of its most important functions is in connection with respiration. By dividing the vagi on both sides in the case of the dog there is a diminution in the case of respiration. Gradually the respirations become slower, the condition of the dog becoming gradually weakened. Inspiration becomes slower and of longer duration while expiration becomes labored and sudden. The respiratory action seems to take place with difficulty. Death results in four or five days, respiration having gradually decreased and the lungs after death being characteristically solid and filled with blood. The pneumogastrics represent the pathway of sensory impulses from the lungs to the medulla, these inpulses arousing reflexly the respiratory movements. In the case of their division these impulses are lacking and hence there is a diminution of respiratory action, not an entire cessation because other impulses pass to the medulla in connection with circulatory action. There is no immediate dyspnœa when the pneumogastrics are divided. If the pneumogastrics are divided at the middle portion of the neck the inferior laryngeal branch is here interfered with, resulting in the paralysis of the laryngeal muscles so that the glottis becomes soft and collapsed and thus forms an obstruction to inspiration. In this way there is a diminution of the amount of air passing into the lungs and the blood ceases to be fully oxygenated so that the impulses to the medullary center are very largely diminished. In connection with the superior laryngeal branch of the pneumogastric we find the connection established with the laryngeal mucous membrane. This forms a necessary protection in connection with the glottis which interferes with the entrance of foreign substances. Hence when a foreign substance passes into connection with the vocal cords or the enfoldings of the glottis there is aroused a stimulation which produces a sympathetic cough, the impulse passing along the superior laryngeal nerve so as to be reflected in connection with the thoracic and abdominal muscles.

In connection with the larynx we find also vocalization, this vocalization taking place in connection with expiration, the air passing out vibrating in connection with the glottis, this vibration being modified by the pharynx, the mouth and the nasal passages. In connection with the vocal cord we find also a certain degree of tension so that when the air is driven out through the glottis between the vocal cords when vibrating variation in sound is produced; thus vocalization takes place in connection with the larynx so that if the pneumogastric or the inferior laryngeal branch is divided on the two sides there results a loss of vocalization. In connection with deglutition we find the completion of the process in connection with the pharynx and the œsophagus which are furnished with sensory and motor fibres by the pneumogastric. The inferior pharyngeal constrictor and the cervical part of the œsophagus are innervated by the inferior lar-

yngeal and the thoracic part of the œsophagus by the main trunk of the vagus. Hence deglutition is interfered with by division of the pneumogastric, both in connection with sensory and motor action in the œsophagus. In connection with deglutition it is necessary that respiratory action be suspended, this suspension taking place in connection with a nerve impulse which accompanies pharyngeal contraction. When the pneumogastric is divided the stomach action is interfered with, the pneumogastric supplying the stomach mucous membrane with sensibility and furnishing impulses to the muscular coating which forms the basis of peristatic action. When the vagi are divided in the neck there is no interference with the sensation of hunger and according to Bernard gastric juice secretion is suspended although it has been found that by introducing food in small quantities directly into the stomach the gastric juice secretion takes place. According to this gastric digestion and secretion are not directly controlled by the pneumogastric, although when the vagi are divided these are destroyed, chiefly because of the paralytic condition induced in the gastric muscles. The vagi thus supply sensory and motor action to the stomach necessary to digestive action. The pneumogastric fibres to the heart arise partly in connection with the superior laryngeal uniting with the cardiac nerve that passes to the heart from the superior cervical ganglion. Other fibres pass from the main trunk of the pneumogastric in connection with the anastomosis with the cardiac nerve from the superior cervical ganglion. The inferior laryngeal branch furnishes fibres to the heart in connection with the plexus in which are associated the laryngeal and the cardiac fibres. Minute branches of the vagus reach the heart in connection with the cardiac plexus originating either from the pneumogastric or passing through the sympathetics. By stimulating the pneumogastric there is a lessening of the cardiac pulsation and by increasing the stimulation the heart action is slowed and by still further increasing the stimulation the heart may cease to pulsate altogether. This stimulation takes place as applied to the pneumogastric electrically. Under these conditions when the heart stops it is in a condition of relaxation filled with venous blood. By dividing the pneumogastric and applying an electric current to the central end there is no interference with the heart action but when stimulated peripherally there is a cessation of the heart action. Thus the impulse that passes through the heart passes from the center downward. When the pneumogastric has been stimulated to the point of ceasing its pulsation, by continuing the stimulation there are found to be intermittent pulsations at first with large intervals and later almost normal. This seems to indicate that the action which has stopped the heart becomes exhausted. The pneumogastric nerves seem to act upon the heart almost like an ordinary motor nerve in connection with the muscle, the difference being that the stimulation of the vagus produces in connection with the heart relaxation.

(l) The spinal accessory or 11th nerve arises from the nuclei in the medulla and from roots of the spinal cord in the anterior horn down to the fifth or sixth cervical. This nerve is so called on account of its spinal origin, one root representing an accessory nucleus in the medulla associated with the vagus nucleus and the other root being associated with fibres arising from the cervical portion of the spinal cord. These fibres unite together into a delicate root which passes up between the anterior and posterior roots to the foramen magnum where it passes into the cranium where it unites with the fibres that spring from the medullary nucleus,

the main trunk passing down along with the vagus and glosso-pharyngeal through the jugular foramen. It is a motor nerve and sends out an external branch which supplies the sterno-mastoid and the trapezium muscles during the expiration of air. In vocal sounds it acts in conjunction with the glottis through its internal glands. It sends out nerve fibres through its internal branch that join the vagus supplying the laryngeal muscles and furnishing cardio-inhibitory fibres to the vagus. In its passage through the jugular foramen the spinal accessory becomes attached to the pneumogastric in connection with its jugular ganglion. As soon as it passes out of the foramen it is divided into an internal branch which passes along with the pneumogastric trunk ard an external branch which passes down to the sterno-mastoid and trapezium muscles. The internal branch consists of fibres whose origin is in the medulla whereas the external branch consists of fibres that originate in the spinal cord. If the spinal accessory is stimulated within the cranium centrally there is no sensitiveness resulting in any part of the body. The fibres undoubtedly terminate in connection with muscle tissues and by its division there is a loss of motor power. The method adopted in experimenting in connection with this nerve is that followed by Bernard, namely, that of evulsion or tearing away forcibly of a part of the nerve. By forcible tearing away of the whole nerve in connection with its point of exit from the jugular foramen either the medullary part or the external branch or the whole trunk may be drawn out. The result is found to be associated with paralysis of the internal branch. It is in connection with this branch that the pneumogastric gets the greater number of its motor fibres. In connection with this tearing out of the spinal accessory on the two sides there is a loss of the power of vocalization and an interference with the action of the glottis to a slight extent, the voice being entirely lost In th ecase of the tearing out of the spinal accessories there is paralysis of the muscles concerned in vocalization, namely, those movements that are associated with the vocal cords and the glottidean rima. The larynx has two functions to perform and it is furnished with motor connection from two different nerves. In vocalization the impulses originate in the spinal accessory while the respiratory impulses originate in connection with the facial, the hypoglossal and the cervical nerves in their connection with the pneumogastric. Thus when the spinal accessory is torn out the respiratory movements which consist of the opening of the glottis and the separation of the vocal cords are not interfered with. The external branch of the spinal accessory is distributed to the trapezium and sterno-mastoid muscles although these muscles also receive motor fibres from the cervical spinal nerves. Even after the tearing out of the external branch of the spinal acccessory the power of motion is still found in connection with these muscles. According to Bernard the external branch of the spinal accessory has a function to perform in opposition to respiration. During the time when muscular effort is being performed, particularly if it is proionged, there is a suspension of respiration. For example, in lifting or straining the muscles the head and neck assume a position of fixation in connection with the sterno-mastoid and trapezium muscles. If these muscles become paralyzed by the division or evulsion of the external branch of the spinal accessory these movements are impossible. Bernard claims that the external branch also supplies motor action in connection with the prolongation of vocalization. If the external branch is divided there is capacity of vocalization bnt the vocalized sound cannot be prolonged so that there seems

to be a motor influence conveyed through the external branch to the muscles in connection with a prolonged cry. Thus the sterno-mastoid and the trapezium muscles are innervated in connection with two sets of motor fibres, those from the spinal accessory which furnish the basis of prolonged muscular effort and of prolonged vocalization and those from the cervical spinal nerves which furnish the impulses connected with locomotion.

(m) The hypoglossal or twelfth nerve originates in the lower portion of the floor of the fourth ventricle supplying with motor fibres the extrinsic and intrinsic muscles of the tongue. It originates from two large nuclei in the lower part of the calamus scriptorius and one smaller nucleus in the same region. It represents the motor nerve to the tongue. It establishes connection with the superior cervical ganglion in connection with the sympathetic in connection with which vasomotor fibres are furnished to the lingual blood vessels. There is also a connection from the ganglia formed plexus of the vagus in connection with the small lingual branch to the hypoglossal arch. These fibres represent the sensory fibres in connection with the lingual muscles. The hypoglossal is connected with the upper cervical nerves by the ansa hypoglossi, these fibres running along the descending noni to the sterno and omo-hyoid and sterno-thyroid. The descendeus noni forms with a branch from the upper cervical plexus a loop from which twigs serve to supply the infra-hyoid muscle. If it is divided the muscles of the tongue become paralyzed preventing articulation and rendering deglutition difficult. This nerve is essentially a motor nerve. By exposing it where it is found above the hyoid bone its stimulation results in spasmodic action on the part of the tongue. If the peripheral end of the nerve is stimulated after division the same result follows, this result depending upon a direct stimulation passing along the nerve to the tongue. Outside of the cranium it possesses sensory fibres but this is due to anastomosis in connection with the first and second cervical nerves at the cranial base, and in connection with the branches of the fifth nerve. Its sensibility is connected with the muscle substance of the tongue and has no bearing upon the lingual mucous membrane. This is evident from the fact that by dividing the lingual branch of the fifth and the glosso-pharyngeal there is an entire loss of sensibility in connection with the surface of the tongue. Even after the division of the hypoglossal the tongue does not lose its sensibility. By the division of the two hypoglossal nerves the tongue loses its muscular power without any loss of the taste or tactile sensations. The lingual movements are essential in connection with the masticatory process as a means of bringing the parts of the food into proper place in connection with the teeth and removing those parts which have been ground by the teeth. The lingual muscles therefore are necessary for mastication so that if the hypoglossal nerves are divided the mastication process becomes difficult. The tongue in connection with the lingual muscles has an important function to perform in connection with the consonants except the labials and and the labio-dentals so that if the hypoglossal is cut there is a lingual paralysis that interferes with articulation. In the human subject a diseased condition of the hypoglossal is almost always limited to the one side. Where there is such a lesion it is most commonly of central origin and affects not only the action of the tongue but also has an important bearing upon other muscles, although one of the first signs is the difficulty in articulation.

As we have seen all of the cranial nerves may be compared to the anterior and posterior roots of the spinal cord but this relation has not as yet been developed. The centers with which these cranial nerves are associated are placed differently from the spinal centers that we find associated with the spinal nerves, the cranial centers being grouped together rather than in regular order. In connection with the 3rd nerve we find the true oculo-motor nerve although the fourth and sixth nerves both furnish innervation in connection with the muscles that move the eyeball. It has been found that there is not only a medullary spinal series of centers in connection with the eyes but also a mechanism that is associated with pupil movements and a muscle which is connected with the alteration in the form of the lens by contraction or relaxation so as to vary the focusing power in connection with objects that are close at hand or far away. Here we find the mechanism associated with the power of combination. The centers associated with this accommodation power are located in connection with the Sylvian aqueduct which represents the prolongation of the spinal canal into the brain. In connection with the fifth nerve we find a union of sensory and motor elements in connection with the jaws and tongue furnishing movement in connection with respiration and mastication. In connection with the eighth nerve we find not only impulses that are associated with the power of audition but also the power of equilibrium. We find in the cerebellum the chief centers that are associated with the power of locomotion and equilibrium of the body. The cerebellum receives sensory impressions from the muscular sense. This, however, is supplemented by the fact that the cerebellum in connection with the eighth nerve receives special impulses which are connected with equilibrium and locomotion, the basis of these sensations being the position that is occupied by the head. As in space we find but three directions so we find three canals called the semicircular canals in connection with the ear. These canals have different planes, a vertical, a horizontal and an oblique and within them we find the endolymph which has the power of stimulating the end organ in connection with the auditory nerve, the stimulation depending upon the direction of the canal. In this way the auditory nerve and the fluid in connection with the three canals forms the organs for the reception of impulses in connection with the position occupied by the head. These impulses are sent to the medulla and then to the cerebellum, the cerebellum becoming stimulated and arousing impulses that are distributed along the different nerve fibres. As we have seen the sensations of taste are provided for in connection with the ninth nerve and a branch of the fifth nerve, so that the different parts of the tongue are capable of taste sensations. In connection with the pneumogastric nerve with which we associate the spinal accessory we find the most important centers that are associated with the functional activity of the lungs, the heart and the alimentary canal. From this standpoint the vagus nerve represents the most important nerve in the body system. The destruction of the center associated with the vagus in the medulla proves always fatal. In connection with the respiratory action it is known that in animals in which the cerebral hemispheres are not fully developed there is still a possibility of carrying on respiration. This points to the fact that the respiratory process depends for its activity on medullary and spinal centers. By experiments conducted by such men as Rosenthal in which he divided the medulla sectionally at different points it was proved that the origin of respiratory rhythm was associated with the medulla. It was

found that this was due to the fact that the vagus nerve has its center in this region. Impulses pass from the lungs to this center and also impulses from other parts of the body which act upon the respiratory center in such a way as to produce rhythmic variations in the center. In connection with respiration we must also take account of the action of the diaphragm and the intercostal muscles, these being innervated from the spinal centers, although these lower centers are under the control of the higher center in the medulla. In the case of the heart there is not necessarily the same action on the part of a special brain center on account of the fact that its muscle substance is capable of an independent rhythm and the ganglia that are found in connection with the cardiac substance forms the basis of intrinsic contractile power. In connection with the medulla we find therefore the chief function discharged by this central center is that of coordination and cooperation in connection with the lungs and the temperature of the body. This brain center represents the cardio-inhibitory center in connection with the vagus nerve. This center is found at the lower part of the floor of the fourth ventricle. The stimulation of this center produces an instant stoppage of the heart pulsation. This same portion of the brain is associated with respiratory action in connection with the vagus and it is this region which has been called the vital knot because here we have the respiratory and cardio-inhibitory centers in connection with the medulla, corresponding with the central orgin of the vagi nerves. In connection with the blood vessels we have also a center in the medulla which is spoken of as the vasomotor center, this center being associated with the change in the caliber of the blood vessels. It has been found that there is a region of cells in the medulla which when stimulated produces a change involving a contraction of all the blood vessels of the body and if extirpated then dilatation of the blood vessels results. Along the spinal cord we have subordinate centers representing the lower centers governed by the center in the medulla in connection with the spinal fibres. The heart is directly associated with this center so that nerve impulses are sent up to the center affecting the center action and modifying the impulses sent out from the center to different parts of the body. We thus see that the medulla represents the seat of the most important actions that are associated with the functional activity of the body organ. It has been found that these medullary centers represent centers that are homologons with the spinal centers that are found associated with the spinal cord.

SECTION IX. The Sympathetic System.

We find two kinds of fibres associated with the sympathetic system. (a) medullated fibres like those in connection with the central nervous system, and (b) non-medullated fibres consisting of gray fibres without the white substance of Schwann. These fibres arise from the sympathetic ganglia. The medulllated fibres arise from the central nervous system. The sympathetic fibre passes through a series of ganglia connecting the ganglia together, these ganglia and fibres extending from the cranial base to the coccyx in symmetrical arrangement on both sides of the spinal cord. If the medullated fibres pass through the ganglia they lose their medullation. Thus the sympathetic system on each side consists of a main trunk with 24 ganglia and minute fibres, the sympathetic trunk being connected with the central nervous system through the spinal

nerves, the connecting fibres being medullated and non-medullated. The majority of the sympathetic fibres are non-medullated, in the lower regions the two main trunks on the opposite sides are connected about the middle line. In the upper regions both trunks unite with the eighth and ninth cranials passing to the cranium along with the internal carotid artery and forming connections with all the cranial nerves except the first, second and eighth. This connection is established directly with the fourth, sixth and ninth, with the third and fifth through the ophthalmic ganglion and with the fifth and seventh through the spheno-palatoid, otic and sub-maxillary ganglia and also with the seventh through the geniculate ganglion; connection is established with the glosso-pharyngeal through the jugular ganglia and the vagus through the pneumogastric ganglia. As the sympathetic fibres are distributed to the viscera numerous plexuses are formed in which the ganglia are found. If the sympathetic is divided in the neck the blood vessels are dilated on the same side increasing the blood supply and the temperature as well as increasing the lachrymal and sweat secretions. If the central end of the cut nerve is stimulated these effects disappear indicating that the sympathetic system furnishes the nerve connection for the walls of the blood vessels so as to maintain them in their normal condition of tonic constriction. These nerves represent the vasomotor fibers of the vessels. The cervical part of the sympathetic supplies the vasomotor fibres of the head. These arise in the cervical region of the spinal cord, coming out by the anterior roots of the lower cervical and upper thoracic nerves. The radiating fibres of the iris originate in the same place, as the división of the sympathetic in the neck produces contraction of the pupil of the eye. The thoracic and upper limb vasomotors arise from the inferior cervical and superior thoracic ganglia and also from the spinal cord in connection with the rami communicantes between the third and seventh dorsal vertebræ. The lower limb vasomotors arise from the cord passing through the sciatic and crural fibres. The pelvic vasomotors arise from the sympathetic ganglia in the abdominal region. The vasomotors of the abdominal viscera are found principally in the splanchnics, some of the fibres being found in connection with the vagus. The splanchnic nerves are three in number, the greater, the lesser and the smallest splanchnics, originating in the human subject out of the thoracic sympathetic ganglia, the greater from the fifth to the ninth, the smaller from the tenth and eleventh and the smallest from the twelfth. The greater and the smaller splanchnics furnish nerve connection to the stomach, spleen, liver, pancreas and intestines. The smaller and smallest splanchnics enter into the plexus that is associated with the kidneys. If these splanchnics are cut the vessels in the abdominal region become engorged with blood. If the peripheral end is stimulated constriction takes the place of dilatation. Thus the sphanchnics furnish the vasomotor fibres to the viscera.

There is a relation between the central nervous system and the sympathetic system. If the spinal cord is divided there is a rise of temperature in connection with the limbs. If the spinal cord is hemi-sected in the dorsal region there is a rise in the temperature in the lower extremity of the opposite side. This of course means dilatation of the blood vessels. If after the section or hemi-section stimulation is applied to the peripheral end of the cord the dilatation gives place to contraction. From this it would seem that part of the vasomotor influence comes from the spinal cord. Some physiologists claim that there are vasomotor

centers all over the cord, although the chief center is found in the medulla. We find the most characteristic distribution of the sympathetics in the thoracic region where the vertebral ganglia are close to the vertebræ. Anterior to these we find another ganglia series which are connected with each other and with the vertebral ganglia, these representing the collateral ganglia. It is from these ganglia that the fibres pass to the terminal ganglia in connection with the tissues and organs. We find a connection between each spinal nerve and the corresponding sympathetic ganglia through the rami communicantes, these fibres being found in connection with the anterior and posterior roots of the spinal nerves. In the white rami we find medullated fibres coming from the anterior and posterior roots of the spinal nerves passing into the lateral and collateral ganglia. The gray rami communicantes consist of non-medullated fibres. In the human subject the four upper rami communicantes as they pass from the upper cervical nerves unite with the superior cervical ganglia, the fifth and sixth unite with the middle cervical ganglia and the seventh and eighth with the inferior cervical ganglia. In connection with the sympathetic ganglia we find cells and bundles of fibres running between the cells, these being bound together by connective tissue which send septa into the central portion of the ganglion. The cells are multipolar, each cell being encased in a capsule, the nuclei being found on the internal surface. The nerve processes pass through this capsule and are connected with the nerve fibres. In connection with the function of the sympathetic system we find an independent as well as a dependent function, the former representing the nerve plexuses which are found in connection with the different organs whose activities may be modified by impulses passed along fibres from the spinal nerve. In connection with these we find the cardaic ganglia, the mesenteric plexus and the plexuses associated with the uterus, Fallopian tubes and ureters. As distinguished from these there are certain fibres whose activity depends upon their established relations with the central nervous system, as for example, the splanchnic sensory fibres. In connection with the cervical sympathetic we find fibres that are associated with the dilatation of the pupils. These fibres originate in the spinal cord, pass out through the last two cervical and first two thoracic nerves into the cervical sympathetic to the head. If the cervical sympathetic is divided the pupil of the eye becomes contracted. The sympathetic system sends out fibres that are associated with the movements of the external rectus muscle. We also find vasomotor fibres in connection with the external ear, the face, the tympanum, the iris, the retina and the blood vessels of the brain and its membranes as well as the œsophagus and the larynx. In addition to these we find secretory fibres as well as vasomotor fibres in connection with the salivary, sweat and lachrymal glands. In the case of the division of the cervical sympathetic in the neck there is congestion in connection with the ear, an increase of temperature varying from three to six degrees and the contraction of the pupil of the eye together with the flattening of the cornea. If the peripheral end is stimulated these results are counteracted by the opposite results, accompanying these being found a salival secretion due to the stimulation of the secretory fibres. In connection with the dorsal and abdominal sympathetic we find in connection with the sympathetic part of the cardiac plexus accelerator fibres in connection with the heart from the lower cervical and the first dorsal ganglion. We also find vasomotors

that pass through the sympathetic to the cutaneous surfaces of the body, the lungs and the extremities. In the cervical sympathetic and the splanchnics, we find fibres which when stimulated centrally produce stimulation of the cardio-inhibitory center in the medulla. We also find the solar and mesenteric plexuses as well as the secretory fibres in connection with sweating. In the abdominal part of the sympathetic we find the vasomotor and motor fibres in connection with the spleen, the bladder, the large intestine, the uterus and the ureters. If these fibres are stimulated there is an increased activity in connection with the organs that are supplied. If the nerves are divided the blood vessels become dilated and there is an interference with the circulation of the blood and also with the nutrition of the different organs.

The sympathetic system is so closely associated with the cerebro-spinal system that it is impossible to separate the two. This does not mean that the sympathetic system has not independent functions, for though it depends upon the cerebro-spinal system it has an independent influence, for example, upon the circulation and in connection with the functions of the visceral life. It is itself the originator of activity. It does not represent simply a pathway for impulses but has within itself all the essential features of a nerve center. There are certain relation between the two system which indicate that they are inseparably associated. For example, the majority of the rami communicantes have their center of trophic influence in the spinal cord only a few having the trophic centers in the sympathetic ganglia. This does not of necessity prove that these rami have their center of functional activity in the spinal cord. The majority of the rami do not pass through the ganglia but pass along the side of the ganglia and unite with the sympathetic trunk. In the case of the vasomotors of the arm and the leg we find the origin in connection with the roots of the brachial plexus, the sciatic ond crural nerves and no origin from the ganglia. In the case of lesions in the cervical region of the cord we find vasomotor paralysis in connection with the dilatation of the one side of the head and of the pupil of the eye similar to that found in connection with a lesion of the cervical sympathetic ganglion. If the spinal cord is divided in the lower part of the dorsal region there is a dilation in the leg on the same side and an increased temperature; if the semi-section takes place in the middle of the dorsal region or at the upper part the dilatation in the leg is increased on account of the fact that the vasomotors to the leg have different origins. In the case of injuries to the spinal cord at any point there may be a loss of tone on the part of the portions of the body supplied with vasomotor nerves below the point of lesion in the cord. While it is true that there is a close relation between the sympathetic and the cerebro-spinal systems the sympathetic ganglia are to a certain extent independent. In the case of parturition it has been found that the foetus has been delivered at abnormal time indicating that there is a capacity of trophic nutrition and circulation although there is only a sympathetic system without any cerebro-spinal system. Even when the cerebro-spinal centers are destroyed the nutrition of the system may be carried on efficiently through the sympathetic system. In line with this it is claimed that arterial tone depends upon the local ganglia that are found in the different parts of the body. It has been found that the vasomotor nerves may be reflexly stimulated in a particular organ or tissue of the body. After dividing the sciatic nerve in an animal it was found that the paws became bloodless while at the same

time by mechanical stimulation there could be produced reflexly a congested blood condition. In connection with the condition of myelitis in which the cervical region of the spinal cord is involved there is not found to be any vasomotor paralysis or anything abnormal in the pupil of the eye. In the case of myxoedema it is found that the sympathetic ganglia possess a degree of independence of function. In the case of the removal of the heart from the body and its continued pulsation as well as in the case of peristaltic movements of the intestines we have evidence of the independence of the sympathetics. If the peripheral end of the cervical sympathetic is stimulated the eyeball becomes protruded, whereas, the simple division of it produces a sinking of the eyeball. There is no doubt that we find certain automatic and reflex actions associated with movement and secretion depending entirely upon the sympathetic ganglia. After the division of the spinal cord in the middle of the dorsal region, at least in the mammals, by the stimulation of one of the hind limbs in connection with the sensory fibres there may be produced an increase of temperature in the other limb. Anatomically the sympathetic system is rich in nerve elements such as are found associated with the central system and also we find an abundance of branches in connection with the sympathetic system which makes it almost certain that the sympathetic system possesses a degree of independent function. This does not mean that the sympathetic system is entirely independent of the cerebrospinal system because the unity of the nervous system forbids the independence of either. In the body system there is a minute nervous system extending to all the body parts and organs so that within definite limits a small part of the body may be supplied for a time by the nervous system found within this small part. The minute elements of the nervous system are grouped together around a center each organ having its own center or series of centers in plexuses or ganglia, union taking place in the case of all of these for common purposes in connection with the body system. The central trunk of the sympathetic system is to unite all of the different parts of the body system so as to harmonize the animal and vegetable life. The question arises whether in connection with the sympathetic ganglia we find the basis of reflex action. We have seen that the spinal cord and the medulla contain the chief reflex centers in connection with vasomotion. In the case of the heart there is undoubtedly a reflex nerve circle within the cardiac substance so that reflex action may be excited not only in connection with the spinal but also the sympathetic nerves.

If all the nerves that unite the submaxillary gland to the medulla are divided there is still a possible reflex action. By dividing the superior cervical ganglia from the higher centers there is still a possibility of the contraction or dilatation of the pupil of the eye reflexly. The same phenomena in connection with vasomotor contraction and dilatation can be stimulated in the case of an arm or a leg cut off from the spinal centers by the division of the spinal nerves. This has been taken by some to indicate that the vasomotor ganglia inside the arm or leg are independent. This does not prove, however, so much, for while the main artery unites the arm or leg to the body there will still continue to be connection by vasomotion through the arterial system in connection with the spinal cord. It is found that pigmentation takes place in connection with the frog when the brain and the spinal cord have been destroyed by reflex stimulation of the sensory nerves, the sympathetic ganglia representing

the reflex centers. In connection with the uterus we find ganglia which possess within themselves reflex power as it is found that even after the death of the mother parturition can take place by the independent action of the uterine centers. Similarly after death there may be a foecal discharge, this discharge taking place in connection with the intestinal sympathetic ganglia. The inferior cervical ganglion seems to possess the function of reflex action. In the case of the injury of the nerves of the brachial plexus there is a shock communicated to the inferior cervical ganglion from which it passes to the vertebral artery producing dilatation, the dilatation being first noticed in connection with the peripheral branches in which is found an increased quantity of blood. In connection with the inferior cardiac nerve through this ganglion there may be also produced a great acceleration of the heart action. The reflex actions of the sympathetic ganglia in the abdominal region are very numerous. A mechanical blow in connection with the solar plexus may produce syncope; conditions of indigestion may produce vertigo, palpitation and even unconsciousness; the stimulus arising from the passage of a gall stone may reflexly produce vomiting. There are examples of reflex activity manifested by the sympathetic ganglia in connection with the reflex arcs. This is particularly the case in connection with cases of emotion or of neurotic pathological conditions. In cases of hysteria arising from uterine or oavrian conditions or depending upon some pelvic conditions we find resulting vomiting, diarrhoea, vertigo, abnormal respiration, dilated pupil, tears, etc., all these representing afferent stimulation in connection with the solar plexus passing from thence along the sympathetic ganglia to the cervical ganglia from which stimuli pass to the cord, the medulla and the brain. The stomach may be irritated reflexly in connection with certain pathological lung conditions and also certain lesions of the kidney. In some cases of paraplegia it is claimed that the paralysis is associated with the sympathetic system. Brown-Sequard has shown that the vaso-constrictors can be stimulated in the pia mater of the spinal cord and in the spinal cord itself reflexly by stimulation. He ligatured the renal nerves on the same side as the spinal pia mater producing constriction of the spinal vessels and resulting in paralysis. The same paraplegia conditions may be produced by uterine conditions, by ulcerative dysenteric conditions as well as by diphtheritic and neuralgiac conditions and inflammatory conditions fo the colon, lungs and pleura. In connection with constipated conditions produced by stimulation of the renal calculus the same reflex paralytic condition has also been found and it is claimed depends upon reflex irritation. It is certain that irritation found in connection with the body organs may be passed to a sympathetic ganglion, the ganglion forming the center of reflex action. This is seen in irritated stomach conditions depending upon pathological lung conditions as well as in the effect upon the heart of mechanical irritation of the solar plexus. The question is, can such a stimulation be reflected through a ganglion so as to produce constriction permanently upon the blood vessels? Some instances have been given in which reflex irritation and reflex paralysis so produced have been continuous for a considerable period.

In connection with vasomotion the chief function is that of constriction, some believing that constriction is the only function of the nerve action, dilatation representing a paralytic condition of the constrictors. It has been fully demonstrated that dilators exist in connection with the kidneys, the nervi erigentes, the glosso-pharyngeal, the superficial

petrosal and the carotid plexuses. Some have claimed that the dilators are found in connection with the constrictors, whereas, the larger number claim that the blood vessels are innervated by double fibres, the constrictors and the dilators. In connection with the reflex action in the vaso-motor system it has been found that by dividing the sciatic the vessels in connection with the muscles on the opposite side become contracted and there is a fall in the temperature, the reverse being true in the opposite side. Vulpian claims that the contraction is produced reflexly by the stimulation of the sensory sciatic nerves. It is claimed that by stimulating the sensory nerves in any portion of the body the blood vessels become contracted. It has been found that after dividing the cervical auricular nerve supplying the ear of the rabbit and stimulating the central end the blood vessels of the ear become dilated, this result being a dilated reflex action. Similarly by stimulating the vagus according to Cyon there is a dilatation of the abdominal vessels in connection with the splanchnic dilators. Thus throughout the alimentary and urinary regions of the body there are continuous variations in connection with the blood circulation taking place reflexly. The contraction of all arteries is not the same, for example, the cerebral, spinal and glandular arteries are most contractile while the veins although in a sense contractile are not subject to contractile action under stimulation, particularly the cerebral veins and the dura mater sinuses. In the case of the nervi erigentes they originate in connection with the sacral plexus, particularly the first and second sacral nerves. passing along the sacral sides towards the posterior part of the bladder and the prostate where they unite with the hypogastric plexus. After leaving the plexus they communicate with nerve fibres which have connection in the corpus cavernosum. In addition to these nerves the pudic nerves supply this region although they have no influence upon the circulation. Their chief function is in connection with the passage of the afferent impulses in connection with erection. Erection depends upon cerebral stimulation arising from the direct stimulation of the vaso-dilators in the erector nerve or reflexly in connection with the spinal cord. In connection with the iris we find the element of contractility but the iris movements do not depend upon changes in the blood vessels, but rather upon changes in the muscle fibres. By stimulating the chorda tympani there is produced dilatation, this dilatation being independent of the secretory action in connection with the submaxillary gland. The dilator fibres seem to exert an antagonistic action to the constrictors, being of the nature of an inhibitory action. By dividing a dilator nerve such as the chorda tympani there is no change produced in the color of the tongue, fibres passing from the sympathetic to the tongue along the lingual artery. It is probable that the vasomotors in connection with the sympathetic represent the constrictors while the dilators represent the cerebro-spinal nerves. It is thought by some that the dilators are also sympathetics being associated in some way with the constrictors. There is certainly a mutual action of the dilators and constrictors, this mutual action producing the vascular tonicity. If the great sympathetic is divided the blood vessels become abnormally dilated. One of the chief functions of these dilator and constrictor fibres is to preserve vascular tonicity. In this function the brain, the spinal cord, the gaglionic plexuses in connection with the arterial walls and the sympathetic ganglia play an important part.

although the sympathetic ganglia seem to play a very important part in connection with the vasomotor centers that are found in the medulla and the spinal cord.

The motor fibres that are associated with the contractions of the blood vessels are the fibres that spring from the ganglia of the sympathetic system, passing along the arterial wall and into the middle coating of the arteries. This vasomotor mechanism is in a condition of constant activity. The tonicity of the vessels is subject to modification depending upon the vessels themselves as well as other parts of the body. This contractile condition seems to be produced by two sets of fibres, the one counteracting to a certain extent the other, as we find in the case of the vagus and the sympathetic in relation to the heart. The larger arteries are both elastic and contractile while the small arteries are only contractile. It has been claimed that in the case of death there is a stimulation of the arteries which empties them of blood, the venous blood stimulating as it is thought the vaso-constrictors. It seems more rational to suppose that the dilators which are less numerous and possess less functional activity in their death remove the inhibition upon the constrictors so that the constrictors contract the vessels abnormally and thus empty the vessels of blood. It is fonnd that vascular tonicity is destroyed by the destruction of the medulla, but that it is necessary to destroy in addition to the medulla the spinal centers in order to cut off reflex impulses. It is found in the case of the child after birth without any cerebro-spinal centers that there is the existence of vascularity depending upon the reflex centers in the sympathetic ganglia. This reflex apparatus depends for its stimulation upon the undulations of the blood in its circulation through the vessels. Hence in the blood vessels we have all that is necessary to sustain this reflex action in connection with the sympathetic ganglia, the sympathetic fibres and the medullary spinal center. It is not necessary that the mudullary spinal center be regarded as the center of these reflex actions. The ganglia in connection with the vessel walls or the ganglia of the cardiac plexuses may act as centers in connection with these reflex acts. Whatever produces paralysis of the constrictors in the blood vessels produces an increase of blood pressure; hence, whatever, abnormally irritates the dilators produces an increase in the blood pressure. Hence the normal vascularity of the blood vessels is opposed to the abnormal increase of the blood pressure. By stimulating excessively the sympathetic ganglia the arterial blood pressure may be increased and there may be produced a palpitation that will temporarily overbear the normal constriction. If the vagi and the other cardiac nerves are divided heart action would still continue for a time in connection with the cardiac ganglia. The ganglia that are found within the heart represent the reflex centers in connection with which the stimulation of the blood passes to the muscles. Aside from cardiac lesions involving the valves or paralysis of the sympathetic nerves there may be a lowering of blood pressure in the arteries chiefly in connection with the depressor nerve. By dividing this nerve and stimulating its central end there is a lowering of the blood pressure and at the same time a slowing of the heart action. In connection with depression there is a reflex action in connection with the splanchnics resulting in the dilatation of the intestinal blood vessels, a free channel is provided for the passage of blood from the arteries to the veins and so the pressure is lowered. Thus it does not depend upon the action

of the constrictors but upon the reflex inhibition of their action depending upon the stimulation of the depressor nerve. The tension that is found in anaemia has been explained as partly depending upon the difficulty in the passage of anaemic blood through the capillaries and chiefly due to the contracted conditions of the arterioles depending upon the stimulation of the vaso-motor center, this stimulation taking place by the deoxygenated blood. We do not find any vaso-motors in connection with the pulmonary circulation and hence in anaemia the blood passes very freely through the lungs. The acceleratory fibres to the heart pass from the inferior cervical ganglia along its third branch. The only direct action of the spinal cord upon the heart is through this nerve. The fibre branches that pass from the cervical ganglia and the cervical sympathetic govern the action of the heart. By the use of the induced current in connection with the vagi there is no change in the cardiac vessels although there is a stoppage of heart action. No influence is exerted upon the heart vessels from the inferior cervical ganglion. The cardiac branches of the sympathetic when stimulated may produce an increase of heart action and a decrease of the systolic period. Some discussion has taken place as to the location of the accelerator centers, some claiming that these are in the praefrontal and the post frontal convolutions, although these are more likely to represent the vasomotor centers the increase of heart action depending upon the change in arterial pressure. Others claim that the centers are in the cervical region of the spinal cord, the fibres passing out from the cord by the rami communicantes down to the sixth dorsal. the higher fibres in connection with the superior and middle cardiac nerve and the lower cervical nerve uniting with the thoracic nerve branches at the Vieussens loop and forming the inferior cardiac nerve. The sympathetics also act indirectly upon the heart through the reflex stimulation by the depressor nerve. The vagus represents the inhibitory nerve of the heart. The vagi connection with the cervical sympathetic is close. In connection with the ganglia fibres are sent out to the superior cervical ganglia and branches are also received from the same organ. Here we have an example of dual inhibition. If this did not exist, where the cervical sympathetic is injured the vagi action would produce paralysis of the cardiac motivity. If the vagus and the, spinal accessory were injured. then without this dual inhibition, no inhibition would be found in the case of the heart so that the heart would be allowed to accelerate its action without any limit. In the union of these two opposing systems of nerves there is an influence exercised over the heart arising from the vagus in connection with the cerebral center and the ganglia of the vagus down to the sixth dorsal and possibly to the first lumbar, this action producing the balance of cardiac action. The cardiac action may be sustained through the influence of the sympathetic cardiac ganglia. It is more probable as we have seen already that the rhythm of cardiac movements depends upon the muscular tissue, as this rhythm is found in connection with the embryonic heart so that the heart rhythm is really independent of the nervous mechanism. The vagus undoubtedly exercises an influence upon the muscle tissue as a trophic fibre rather than as a motor fibre.

The glands of the body are not only in relation to the circulation through the blood vessels but also in close relation with the nervous system. There is an increase of gland secretion in connection with emotional conditions. All the glands of the body are subject to both the

cerebo-spinal and the sympathetic action. According to Bernard the cerebro-spinal represents the stimulator or vaso-dilator and the sympathetic the moderator or vaso-constrictor. In salival secretion the submaxillary and sublingual glands are supplied by the chorda tympani and the parotid by the small supficial petrosal, representing branches of the facial nerve. These branches represent the dilator and constrictor fibres while the sympathetics represent the constrictor fibres. Some claim that in the sympathetic we find secretory fibres arising at the third or fourth dorsal but this is denied by others who say that all the secretory nerves are found in connection with the cranial nerves. As yet there is no proof of the existence of secretory fibres in connection with the sympathetics, although some think that the cranial nerves provide the secretory fibres in connection with the water element and the sympathetics the secretory fibres for the organic elements. Experiments indicate that secretory action does not depend upon the character of the circulation but depends directly and reflexly upon the nervous connection of the gland. This does not prove that the increase of blood does not produce an increased secretion but simply that the secretory action must involve the secretory nerves. Salivation secretion is a reflex action, stimulated by lingual movements or the presence of a substance in the mouth. It is also dependent upon the stimulation of the special sense of smell, sometimes that of sight and also sometimes that of hearing in connection with some sapid substances. In connection with the lachrymal glands the chief nerve of secretion is in connection with the fifth. The experiments seem to indicate the sympathetic has a controlling influence over lachrymation as in the case of emotional conditions. The stimulation of the sympathetic increases lachrymation although the secretion in this case becomes more viscid. In conneetion with lactation it seems that it depends largely upon the circulation in the gland, although the secretory nerves play an important part, the cerebro-spinal coming from the fourth and fifth dorsals. The mammary gland is very subject to reflex stimulation, the first secretion of milk depending upon the stimulation aroused by the movements of the foetus within the uterus. This stimulation aroused in the uterus may pass through the sacral plexus to the spinal cord and pass up along the cord to the point where the mammary nerves are given off at the fourth and fifth dorsals or if the stimuli are strong they may pass to the brain and thence descend to the mammary nerves in the dorsal region. These stimuli may also pass from the uterine ganglia through the sympathetics to the semilunar ganglia and may thence pass to the ganglia of the sympathetics in the dorsal region and thence to the mammary gland or to the spinal cord and thence to the gland. The afferent impulses may be aroused by simple touch and this forms the beginning of the purely reflex action associated with lactation. In connection with lactation it is necessary to avoid emotional conditions and also conditions of indigestion, these indicating the sympathetic influence over the mammary secretion. If a substance is not easily digestible stimulation may be excited in connection with the plexus beneath the mucous membrane of the stomach which may pass to the nerves of lactation and thus influence the secretion.

In connection with sweat secretion we have a distinct set of fibres probably the secretory fibres being cerebro-spinal and the sympathetic fibres representing the moderating or inhibitory fibres or vaso constrictor fibres. Physiologists do not agree as to whether the secretory fibres are cerebro-spinal or sympathetic. Some claim that the nerves in connection

with the lower parts of the body are found in connection with the abdominal sympathetics leaving the cord in connection with the first four lumbar aad last theee dorsal nerves; for the upper part of the body they are said to be found in the spinal nerves in connection with the superior thoracic ganglia. By dividing the cervical sympathetic it is found there is an increase of sweat on the same side as the division; at tho same time there is not paralysis of vasomotion sufficient to produce the excessive sweating. From this it is concluded that the sympathetic inhibits hyperactivity on the part of the sweat glands and assists in preserving tonicity in the glands. Excess of sweating according to this would depend on secretory fibres passing out from the spinal cord through the rami communicantes to the sympathetic ganglia. The sweat center is supposed to be found in the spinal cord. In excessive sweating we find that the cause is sometimes associated with indigestion or with abdominal irritation of some kind indicating that the action is a reflex one. The sweat secretion is associated with vasomotor paralysis. That this is so is proved by the fact that if the vasomotor centers become paralyzed then the vascularity of the sweat gland is altered producing a bloody sweat.

In connection with the stomach we find that the splanchnics represent the dilator and constrictor fibres. The vagus has no vasomotor connection with the stomach. Injuries at the base of the brain sometimes produce a softening of the stomach. The gastric glands are subject to the control of the sympathetic system, the fibres originating in the solar plexus and the semilunar ganglia sometimes influencing the gastric glands independently of the action of the cerebro-spinal system. The vasomotors regulate the amount of blood while the secretory fibres are probably fibres from the pneumogastric. The gastric glands are stimulated chiefly by the presence of food in the stomach, the stimulation of some of the nerve fibres leading to the stomach not producing any effect upon the stomach. Even if the nerves to the stomach are divided the secretion will go on without interruption. This indicates that the ganglia found in the stomach walls may act as centers of secretory activity. The most generally accepted theory is that the vagi represent the secretory fibres and the sympathetics the constrictor fibres. This close sympathetic relation of the stomach furnishes the reason why the gastric secretion is so easily affected by stimulations originating in the kidneys and lungs, etc. In connection with the liver the secretory influence in connectirn with vasomotion passes through the splanchnics while the true secretory influence passes from the hepatic plexus, the fibres arising from the solar plexus. Lesions in the solar plexus are found to produce an increased bile secretion; a similar change taking place in the case of lesions in other organs. It is possible that the influences which pass to the liver through the hepatic plexus originate in connection with the fibres from the vagi. In connection with the kidney the nerve fibres originate from the greater splanchnic and from the solar plexus while a few fibres pass directly from the solar plexus and a few from the small splanchnic. It is probable that there is here an opposition between the vagus and the splanchnic, the mutual action of these two nerve connections forming the basis of normal renal action. If all the nerves passing to the kidney are divided or if the greater splanchnic alone is divided there is kidney congestion. If the peripheral end of the divided splanchnic is stimulated there is a cessation of the flow of urine. Thus the splanchnic supplies in part the vasomotor fibres to the kidney. Both the dilator and the constrictor fibres are found

in connection with the splanchnic. Much discussion has taken place as to whether the urine is the secretion of a gland or simply a filtering process representing a true excretion. If the sympathetic is divided in the neck or if the cervical sympathetic is divided there is found to be an excess of urine, indicating that the cerebro-spinal centers influence the kidneys through the sympathetic system. It has been found that by puncturing the floor of the fourth ventricle close to the point at which the diabetic puncture is made there results an excessive increase of urine. This seems to indicate that the vaso-motor regulation of the renal blood supply takes place through the splanchnic. It is found that by irritating the sympathetic trunk from the fifth vertebral that there follow movements of the small seminal pouches at the base of the bladder called the vesiculæ seminales. The fibres which produce this stimulation originate in connection with the general spinal center. The testicular secretion is subject to the influence of the emotions, indicating the action of the sympathetic system. The secretory fibres spring from the spermatic plexus branching off from the renal plexus. In connection with the renal plexus it is closely connected with the small splanchnic and with the spinal cord. The vasomotor fibres also arise from the spermatic plexus and are found distributed in connection with the branches of the spermatic artery. In all of these secretory actions we find the principle of dual inhibition in connection with vasomotor and secretory fibres, representing both the cerebro-spinal and the sympathetic systems. In connection with absorption we find that the process of absorption is interfered with when the spinal and cerebral centers are destroyed. This indicates that the vascular tonicity is necessary to absorption and that the loss of this tonicity, interfering as it does with the circulation, arrests or destroys absorption. The nutrition of an organ or a part of the body depends upon the blood supply and on the normal action of the absorption process. Both of these functions as we have seen depend upon the regulative action of the sympathetic system. The nerve centers seem to send out a trophic influence which is necessary for the maintenance of the normal condition of the muscle. For example, if the trigeminal nerve is divided beyond the Gasserian ganglion there is only a slight effect produced upon the eye, whereas, if the division takes place between the protuberance and the ganglion the nutrition of the eye is very seriously affected. By the division of the cervical sympathetic in the case of enfeebled animals conjunctivitis and inflammation of the cornea are produced. Similar results follow the extirpation of the superior cervical ganglion. This seems to indicate that by cutting off the nerves trophic influences are cut off from the organs. The spinal origin of the vasomotors in connection with the leg is higher up than that of the sciatic. In the case of muscluar atrophy occurring along with lesions beneath the vasomotor origin this condition of atrophy must depend upon the loss of influences from centers outside of the spinal system. According to Bell muscular atrophy is asssociated with the sympathetic system. According to him in addition to lesions found in the anterior horns the cervical ganglia of the sympathetics are altered or degenerate, several cases being recorded in which degeneration of the sympathetic was found associated with progressive muscular atrophy. One case is recorded of acute liver atrophy accompanied by degeneration in the nerve cells of the sympathetic ganglia. The sympathetic system undoubtedly has some influence upon nutrition, for it influences the processes of absorption and assimilation by

changes in the tension of the blood. In addition to this we have the fact that in the embryo condition nutrition takes place before the distinct appearance of the cerebro-spinal system. This seems to indicate that nutrition is carried on in connection with the nerves which supply the different parts of the body, all the nerves having in addition to the special function a trophic function.

Claude Bernard claims that the vasomotor system represents heat regulation. To a certain extent this is true because vaso-motion regulates the blood movements and therefore regulates the heat loss. In the case of the vessels heat dilates the vessels and produces acceleration of the heart's action, whereas cold contracts the vessels and slows the heart action. The body temperature represents to a large extent the metabolic changes that take place within the body. The vasomotor action in the case of body temperature either produces heat or modifies its exhaustion. Vasomotion regulates the dilatation of the vessels and as the amount of blood within an organ depends upon the heart action the sympathetic system has something to do with body temperature. The sympathetic influence upon animal temperature must depend therefore upon vasomotor action in connection with the body as a whole, vasomotor action in connection with the skin and upon the accelerator fibres that are found in connection with the heart, regulating the amount of blood passing to the tissues and also the amount of oxygen that passes through the lungs. According to Bernard the cerebro-spinal nerves are the heat nerves. because by the dilatation of the blood vessels the increase of blood and of metabolic action there is an increase of heat. The creation of heat depends upon chemical action but its distribution or its diminution depends upon the action of the sympathetics. It is claimed that there is a regulating center in or in connection with the pons Varolii so that if it is obliterated or the nerve fibres to it destroyed there is an increase in temperature. In connection with fever it isclaimed by some that the heat production is not excessive, the increase of temperature depending upon heat distribution subject to nervous action. Others claim that the nervous system has nothing to do with the fever condition but that the fever depends entirely upon an increase in the chemical action of metabolism. According to others we find both an increase in the chemical action and nervous action. According to the first class of writers the vasomotor system is chiefly involved, there being no material change in the heat production, but the heat produced being distributed throughout the parts of the body affected. In a condition of rigor the peripheral blood vessels are in a condition of spasms driving the blood to the interior of the body, thus cutting off the means of heat loss so that there is a great accumulation of heat. After this the peripheral vessels become dilated but as the patient is in a hot temperature under ordinary conditions the heat is not lost. According to those who hold that the heat production is increased on account of the chemical action it is claimed that the increase of temperature does not depend upon vasomotor changes and that the nervous system plays a very small part in the heat accumulation. According to some there is an increased oxidation in the albuminoid substances while the carbon substances cease to be oxidized and give rise to a condition of fatty degeneration. According to Hirtz the vasomotor system has the power to lessen the heat loss. Hence in infectious fevers he finds that the cause of the increased activity on the part of the organic oxidation is the germ that is taken into the blood while in other fevers it is

found in the septic poison. Many consider that the initial cause is to be found in the bacteria that are associated with the different forms of fever. The primary spasmodic condition is aroused in connection with the sensory cutaneous nerves which send to the central nervous system a sensation of cold. The result of this is that the difference in temperature becomes intensified as well as the spasmodic condition. The larger blood vessels and the heart when stimulated by the flow of blood drive out the blood without any control into any open part of the circulation, particularly into the circulation of the spinal cord producing inhibition of some of the centers and excessive activity in others. After this stage the blood passes to the surface of the body, continuing in a heated condition on account of the continued oxidation. Associated with this there is a dilatation of the blood vessels resulting in a slower circulation followed by the absence of sweat and congested conditions involving the centers which produce the characteristic headache and insomnia associated with fevers. According to others there is undoubtedly an increased oxidation but this it is claimed depends upon the increased activity of the nervous system. In the brain it said there is a special center of inhibition which controls normally the oxidation processes, whereas in fevers on account of the paralysis of this inhibitory center there is no inhibition of the oxidation process. This center of inhibition may be paralyzed by any septic or bacterial substances. According to some, heat producing substances irritate the centers of vasomotion producing the spasmodic rigor condition and cutting off the heat loss. When those centers become enfeebled or possibly by an increased toxic action the paralysis becomes more complete, the result being that the tissues are unrestrained in their chemical oxidation. According to some fever consists in a pathological condition of the entire nervous system, the sensory nerves being prominent in this condition at least in local inflammatory conditions. There is no doubt that the temperature depends largely upon an increased activity and the increased activity affects the nerve centers. The nervous system has a direct action in the case of heat production in connection with vasomotion and also in connection with certain fibres that are not vascular. In the case of a high temperature there is a diagnostic symptom of a cerebral lesion, particularly a lesion associated with the pons. What is called traumatic fever does not arise from nervous influence but originates from some injury, the influence passing from some fluid or semifluid substance containing bacteria or bacterial poison passing into the circulation and thus affecting the nerve centers. It is found in the case of fever that various parts of the system are brought into play. In the application of heat externally to the body there is a rise in temperature and at the same time an abnormal condition involving the nervous system, the circulation, digestion and secretion, these changes depending upon the increase in external temperature. This indicates that an increased temperature is a diagnostic symptom of fever. In the case of the division of the spinal cord it is found that the loss of heat is increased and if the section takes place higher than the point of the origin of the splanchnic nerves there is a sudden increase in the amount of heat loss and also in the amount of heat production. The cause of the diminution in the heat production is probably to be found in the vaso-motor paralysis also producing an increased loss of heat so that there is such a lessening of the heat as to interfere with the oxidation processes of the body. The chief vaso-motor center is found in a region

two centimeters below the corpora quadrigemina and four centimeters above the apex of the calamus scriptorius. It has been found that the chief vasomotor center is in the lower part of the floor of the fourth ventricle close to the apex of the calamus. By dividing the medulla at its point of junction with the ponsthere is found to be an increase of temperature in the dog and also an increased heat loss although the loss is less than the production, accounting for the increase in the body temperature. This increase in body heat depends upon the absence of some active force governing the heat production and hence it is claimed that a nerve center is located in this region called the inhibitory heat center which normally inhibits the chemical oxidation processes in the body. To maintain the normal temperature the nervous system must be intact; this includes the vaso-motor action because these nerves by constricting the superficial capillaries and inhibiting the secretions are able both to increase and to decrease the heat loss. Fever represents thus a condition in which a depressent poison seems to act upon the nervous system interfering with its regulative action in the case of the production and the loss of heat. The center becomes paralyzed and does not exert a normal influence upon the system so that the tissue changes take place at a very rapid rate and there is involved metabolic processes to excess. While this heat center is paralyzed the vaso-motor system is also affected to such an extent that they are unable to act normally and are therefore unable to throw off the heat which becomes accumulated to excess within the body system. Congestion results from either direct or vaso-motor paralysis, direct in the case of the division of the cervical sympathetic and in cases in which the spinal cord is injured resulting in an interference with the cardiac circulation. Congestion is reflex when it is stimulated by some sensory excitation as in the case of the division and stimulation of the glosso-pharyngeal nerves. In reflex congestion there is generally a suspension of the tonic action of the vaso-motor centers either cerebral or sympathetic.

The sympathetic system influenced by emotion. Some physiologists consider that the center for emotion is located in the ring-like protuberance, but it is more probable that centers of emotion are to be found in different parts of the cortex. When this center of emotion becomes excited the reaction influence is imparted to the medulla and the spinal cord producing muscular contraction or iufluencing the heart movement, vascular tonicityand internal secretion. These changes that are associated with vascular tonicity sometimes result in a congested condition. the congestion being due to relaxation in connection with the vasomotor centers, the activity of these centers in maintaining tonicity being interfered with. These centers are found in the cervical and upper dorsal ganglia of the sympathetic.

In connection with inflammation there is often a determination of the blood to the part inflamed. The inflammation originates from some kind of irritation, this irritation stimulating the sensory nerves, this stimulation being transmitted to the vasomotor centers which govern the region that is irritated. The result of this is that the tonic action of the centers is interfered with producing an interference with the tonicity of the vessels, a dilatation of the vessels. This interference with vasomotion assists development of the inflammatory condition although it is not of itself inflammation. There is a vital change that takes place place in connection with the tissues as a result of the irritation so that the part becomes morbid. This condition may be produced reflexly. The vaso-

motor action then enters into the inflammatory condition and becomes of importance in the determination of the progressive stages in the inflammation. As to the manner in which the vaso-motor centers either in ganglia or in the central system are irritated it is not definitely known although it is due in all probability to some peripheral irritation resulting in the suspension of the tonic activity on the part of the centers. According to Vulpian this is the true theory of inflammation. According to him in such a condition as pneumonia in addition to the cold that reflexly interferes with pulmonary nutrition there is to be found a predisposition to the inflammatory condition and this latter condition causes the lungs to be more sensitive to the reflex action produced in connection with the cold. This predisposition locally is explained by the presence of the pneumonia microbe. Even although vaso-motor paralysis does not directly influence the first stages of inflammation we find undoubtedly instances in which the action is indirect, arising from the partial paralysis of the vaso-motor centers. This fact has tended to introduce a false conception of the position of the vaso-motors in inflammatory conditions. Very often congestion becomes inflammation and this led some to regard the one as the cause of the other. When a part becomes congested there is gradually malnutrition, the part affected being imperfectly nourished and thus predisposed to influences that produce inflammation. At this point the external influence comes into action still further modifies the nutrition and thus forms the last factor in the production of inflammation. Congestion as we have seen forms a predisposition to inflammation, but this may pass into an oedematous condition. The vaso-motors are brought into play in producing oedema. When the vaso-motors are paralyzed the arteries become filled with blood and the capillaries become dilated and when there is an obstruction to the venous circulation then we have oedema. This oedematous condition may be produced reflexly, associated with dilatation of the vessels arising from some reflex sensory stimulation. The cause of oedema is undoubtedly vital and cannot be regarded as simply due to a mechanical obstruction. It has been found that the ligaturing of the femoral vein did not sufficiently interfere with the circulation to produce transudation and accumulation of serum in the cellular tissue. As soon, however, as the nerves that supplied the vessels were divided the blood flow was interfered with to such an extent that oedema resulted. This seems to indicate that the vaso-motor nerves and centers play an important part in connection with the production of oedema. This indicates that the sympathetic system has an important bearing upon the preservation of the normal condition in the prevention of oedema.

It is found that injuries to some of the nerve centers, for example, lesions in the optic thalamus and the crura cerebri produce extravasation of blood in connection with the mucous membrane of the stomach. Injuries in the thoracic region of the spinal cord may be associated with hemorahage in the suprarenal capsule; injuries to the pons may be followed by hemorrhage in connection with the lungs, the liver, the kidneys and even the heart on the opposite side of the body to that of the lesion. Hemorrhage in connection with the mucous lining of the stomach has been produced by prolonged stimulation of the sciatic nerve, injuries to the auditory labyrinth or to the corpora quadrigemina. These are supposed to be produced by a constriction of the veins producing capillary rupture behind the constriction. In some cases the hemorrhage is produced by vaso-motor paralysis producing first a congested condition

and finally a ruptured condition of the vessels. In connection with the hemorrhage from the nose and in connection with the uterus found sometimes in cases of typhoid fever the hemorrhage is produced by some change in the vaso-motor system, although some claim that it is produced by the abnormal blood condition or by some lesion in the vessel walls. As we have seen already in the case of bloody sweat this abnormal condition may take place with an interference on the part of the vaso-motor mechanism particularly in hysterical cases where the vessels of the sweat glands are interfered with. This arises from a paralytic condition of the vaso-motor centers that regulate vaso-tonicity. Irregular menstrual conditions may produce a vomiting of blood, intestinal hemorrhage, nose bleeding, blood in the urine, etc. All these conditions depend upon the fact that there is a suppression of the menstrual flow producing a change in the vaso-motor centers or nerves. This change produces reflexly the hemorrhage and accompanying it headache, giddiness and tingling sounds in the ear or head.

In the sympathetic system we find certain peculiarities of arrangement and distribution. There is a double cord extending over the body in front with a large number of scattered ganglia, joined together by delicate fibres whose branches are distributed to the different organs of the body. In the sympathetic system we find some nerves that are medullated, although the majority are unmedullated. The chief characteristic of the sympathetic nerve fibres is their smallness and also the smallness of the cells, the sympathetic cells never being so large as those found in the central system. The cells are also characterized by sending out elongated branches which form the origin of new fibres. In connection with all the sympathetic ganglia we find fibers from the cerebro-spinal nerves whose fibres pass through the ganglia in order to reach the peripheral sympathetic branches. This is presumed to be the case from the fact that these fibres do not originate or end in the ganglion and also from the fact that by dividing the cerebro-spinal nerves that communicate with the ganglia paralysis may be produced in the case of an organ that is supplied by sympathetic fibres. For example, by dividing the oculo-motor nerve that supplies the iris with its motor fibre passing through the ophthalmic ganglia the pupil of the eye becomes dilated. Similarly the vagus furnishes many fibres to the cardiac sympathetics and the cardiac plexus. We find in the spinal and cranial nerve roots ganglia that are very similar to those of the sympathetic system. According to this all the body organs receive nerve supply from both the cerebro-spinal and the sympathetic system, the only difference being in the proportion in which the one kind of fibre is supplied to the different organs; for example, the sympathetic fibres have the larger number in connection with the circulatory, secretory and digestive organs, whereas, the cerebro-spinal nerves are greater in number in connection with the organs of animal life. In the sympathetic system we find a chain of ganglia on either side of the spinal cord each ganglion being united through sensory and motor fibres with the cerebro-spinal system. The nerve fibres are given off to the glands and mucous membrane and to the involuntary muscles. The ganglia of the sympathetic system are located in the head, neck, thorax and abdomen and in connection with each of those areas we find nerves distributed to the special organs. The first ganglion that is located in the head area is the ophthalmic ganglion in connection with the eye on the external aspect of the optic nerve. Delicate fibres bring it into communication with the

carotid plexus of the sympathetic. Its motor connection is established with the oculo-motor and its sensory connection with the ophthalmic branch of the fifth. The fibres of distribution are distributed to the eyeball, pass through the sclerotic and end in connection with the iris. The second ganglion is the spheno-palatoid located in the spheno-maxillary fossa. Communication is established between it and the carotid plexus its motor connection being found in the facial nerve and its sensory connection in the superior maxillary branch of the fifth. Fibre distribution takes place to the levator palati and the muscles of the uvula, the mucous membrane of the posterior portion of the nasal passages and to the palate. The third ganglion is the submaxillary ganglion which is in connection with the submaxillary gland. Communication is established with the superior cervical ganglion by means of fibres which pass along the external carotid and the facial arteries. Its sensory fibres come from the lingual branch of the fifth and its motor fibres through the chorda tympani from the facial nerve. Fibre distribution takes place to the submaxillary gland. The fourth sympathetic ganglion is the otic ganglion which is found beneath the base of the cranium on the internal side of the inferior maxillary branch of the fifth. Communication is established by means of fibres with the carotid plexus. Its motor connection is established through the small superficial petrosal with the facial and through the inferior maxillary branch of the fifth and its sensory connection from the tympanic nerve, with the glosso-pharyngeal. Fibres of distribution pass to the internal muscle of the malleus to the mucous membrane of the tympanum, the eustachian tube and the circumflexus palati. As the sympathetic nerve is continued into the neck there are found the superior middle and inferior ganglia communicating with one another and also with the spinal nerves in the cervical region. The fibres pass along the carotid artery and its branches forming the arterial plexuses and being distributed to the thyroid body, the trachea, the larynx, the pharynx and the œsophagus. In connection with the cardiac nerves fibre are also distributed to the cardiac plexus and to the heart. In the thorax the sympathetic ganglia communicate with the spinal nerves in a two-fold way, each of the ganglia receiving two fibres from the spinal nerve that is above it. Distribution of fibres takes place from the ganglia to the plexuses in connection with the lungs, the oesophagus and the thoracic aorta. In connection with the abdominal region we find the sympathetic system appearing in connection with the coeliac artery as the semilunar or coeliac ganglion. In connection with this ganglionic center distributing branches are sent out in connection with the solar plexus, the secondary plexuses being found in connection with the abdominal aorta and its branches, fibre distribution taking place to the stomach, the liver, the intestines, the spleen, the pancreas, the kidneys, the suprarenal bodies and the organs of generation. In the pelvic region we find several pairs of ganglia in connection with the sacrum both anteriorly and posteriorly, the impar ganglion representing the small ganglion on the coccyx which is supposed to represent the union of two symmetrical ganglia. In connection with the sympathetic ganglia we find that both the ganglia and the nerves are sensory and motor, although these sensory and motor functions are not so active as we find them in the central system. In connection with the sympathetic nerves sensory action is more difficult to excite and is less characteristic. In the case of motor activity we find the same characteristic. The sympathetic system in connection with the

head has an important relation to the eye, in connection with pupil movements. The reflex takes place along the oculo-motor nerve into the ophthalmic ganglion and then along the ciliary fibres to the muscle fibres of the iris. Iris movement is characteristically slow and it does not take place immediately but requires considerable time in order that action may result. By dividing the sympathetic nerve in the neck or by removing the superior cervical ganglion the pupil of the eye on the same side is contracted. As soon as this paralysis takes place the straight muscles of the eye having lost antagonistic action it causes a permanent pulling backward of the eyeball and therefore the eyelids become partially closed, both of these results being due to the absence of sympathetic action. It would seem from this that the muscles of the eye are subject to the control both of the central and sympathetic systems, the fibres producing dilatation on passing through the ophthalmic ganglion from the central ganglia of the sympathetics and the fibres producing contraction through the ganglion from the oculo-motor nerve.

The chief function of the sympathetic system is in connection with vaso-motion and its effect upon the general circulation of the body and the local circulation of the parts of the body. The sympathetic fibres and plexuses are found to ramify in connection with the arteries and their branches and fibre distribution finds its terminal in connection with the muscular coating of the blood vessels. In connection with the ramifying fibres there is a contraction of the muscular coating and a consequent diminution of the calibre of the vessel. The nerves which produce this contraction are called vaso-motor and the centers vaso-motor centers. When contraction takes place and the calibre is lessened there is a smaller amount of blood allowed to pass through the vessel resulting in local anæmia. By taking a white rabbit and holding its ear against the light the blood vessels will be found to alter periodically. The central artery passing from the root of the ear to the point becomes branched in connection with the capillary plexus and as the vessels pass out of this plexus they are united into two veins which pass along the margins of the ear towards the root. The central artery and its branches as well as these two veins can be easily seen. The central artery becomes smaller, its branches seeming almost to disappear while the veins receiving a smaller amount of blood also seem to disappear. After a time the artery again becomes larger as the blood passes into it from beneath passing through the ramifying branches. The artery remains in this condition for some time and then contraction takes place again. These variations have been found to take place with more or less constant frequency, indicating that there is a certain degree of regularity in the vascular changes. If the sympathetic nerve is divided in the neck there is a congested condition in the parts of the head on the same side, this effect being particularly noticeable in the ear of the white rabbit. A very short time after the division of the nerve both the arteries and veins become distinctly gorged with blood and there is no longer the periodic rhythmic variation. Associated with this we find an increase in the temperature of the ear and also that the blood becomes less venous an account of its rapid passage through the capillaries; there is also an increased sensitivenesss in the ear The same results are found to be associated with the head and face on the same side as that of the division. This condition is intensified by the removal of the superior sympathetic cervical ganglion and undoubtedly it is due to paralysis in connection with the muscular coating of the arteries

supplied by the sympathetic fibres. If the upper end of the divided nerve is stimulated there is a diminution in the size of the arteries and veins and very soon an entire disappearance of the congestion. This indicates that the sympathetic fibres have a decided action in connection with the muscular coating of the arteries, producing a contraction of the blood vessels resulting in the control of the blood flow through the arteries, in other words they exercise a vaso-constrictor influence. When the nerves are divided this constrictor influence is cut off. As we have seen the vaso-motors in the head region come from beneath passing upward in the cervical sympathetic through the superior cervical ganglion which represents a center of distribution. Its removal cuts off the tonic constriction exercised over the blood vessels of the head and face. At the same time it receives part of its influence below the ganglion because if the sympathetic is divided below the ganglion there is still a congested condition. The ultimate origin of the sympathetic vaso-motors is to be traced to the cerebro-spinal nerves in connection with the cord. The sympathetic ganglia in addition to their connection with one another are united with the spinal nerves by the rami communicantes and in some cases the fibres of these rami can be traced along the spinal nerve to the cord. It was found by Waller that the spinal cord from the first cervical to the sixth dorsal vertebrae there was a region which on being electrically stimnlated resulted in the dilatation of the pupil of the eye; whereas if the sympathetic had been previously divided in the neck the stimulation of the region did not produce pupil dilatation. In this case the stimulation must have passed thaough the spinal nerve and along their branches to the ganglia in the neck and thence along the cervical sympathetic to the head. It has been found more recently that when stimulation is applied to the spinal cord between the second and third dorsal vertebrae the greatest effect is produced in pupil dilatation. Bernard found in the case of the dog that the vaso-motor nerves supplying the head pass from the spinal cord. By dividing the first two dorsal nerves inside the spinal canal he found that the same effect was produced as that which followed the division of the sympathetic in the neck except that there was no increase of temperature and no congestion. By stimulating the peripheral ends of the divided nerves there is found to be pupil dilatation. By dividing the sympathetic high up in the thorax between the second and third ribs no contraction of the pupil takes place. Thus it is found that there is a difference between the sensory and motor fibres and those which supply the blood vessels. The sensory and motor fibres for the head pass out from the base of the brain through the cranial formina to the skin and muscles, those for the blood vessels passing from the spinal cord in connection with the third thoracic, thereafter joining the sympathetic and thence passing to the head. There is also found to be a difference in the sensory and voluntary motor fibres and vaso-motor fibres in connection with the arm and legs. In connection with the arm the vaso-motor fibres originate in the dorsal region of the cord. Bernard by the division of the last three cervical and the first two dorsal nerves found paralysis of motion and sensation in the front limb on the same side in the dog without any congestion. By the removal of the first sympathetic thoracic ganglion or by the division of the nerves from the brachial plexus after their junction with the fibres from the first thoracic ganglion that there was an increase of temperature in the limb on the same side. He found the same result by dividing the thoracic part of the sympathetic between

the third and fourth dorsal. According to Bernard the vaso-motor fibres originate beneath the first thoracic ganglion and according to Cyon from the third to the seventh dorsal nerves. According to Bernard the vaso-motor fibres for the lower limb have an origin of a similar nature. The division of the spinal nerves before they pass to the lumbo-sacral plexus produces paralysis of the lower limb. By the division of the sympathetic between the fifth and sixth lumbar vertebrae there is an increase of temperature in the lower limbs, indicating that the vaso-motor fibres are distinct from the fibres of sensibility and motion. In connection with the sympathetic fibres as they are found distributed in the arterial walls the arteries are maintained in a normal condition of tonic contraction. In this way the circulation of the blood meets with a tonic resistance on the part of the arteries, this tonic contraction depending upon the nervous impulses. This tonic resistance depends upon the action of the sympathetic nerves. In addition to these fibres which maintain tonicity in the arterial wall there are also fibres which produce dilatation, these dilator fibres originating particularly from the cerebro-syinal nerves. In connection with the vagus its stimulation by means of galvanization produces the dilatation of the heart and its engorgement with blood. The same effect is found in connection with the submaxillary gland and the tongue. In this way there is a dilator action in connection with the dilator nerve. the action of which is as yet only very indistinctly understood. It is supposed that there passes from the nerve centers an inhibitory influence which suspends or inhibits the tonic contraction produced by the sympathetic fibres resulting in the dilatation of the blood vessels under the pressure of the blood. When this inhi bitory influence is cut off the sympathetic system renews the tonicity of the blood vessels. In connection with the living body vascular contraction and dilatation are produced reflexly, as for example vascular contraction resulting from the irritation of the central end of a sensory nerve. For example, by stimulating the central end of the sciatic nerve there is a contraction of the blood vessels in other portions of the body. This action passes along the sciatic nerve to the spinal cord and is transmittted to other parts of the body, for example. to the tongue along the sympathetic fibres. This reflex action must take place in connection with some nerve center in which an afferent is transformed into an efferent impulse. The ganglia of the sympathetic system are capable of performing this function, as for example, when the sympathetic nerve is divided in the neck there is vascular paralysis of the head. whereas if the superior cervical ganglion is destroyed the paralysis becomes more characteristic. Vulpian claims that by destroying the brain and the upper half of the spinal cord in the frog the destruction of the cervical sympathetic ganglion results in a congested condition of the tongue on the same side. This seems to indicate that the sympathetic ganglia have an independent influence in connection with the origination of nerve impulses associated with vasculationr. The independent action of tho ganglia is limited however to those portions of the vascular system to which direct distribution takes place. We have seen that sympathetic roots pass out from the spinal cord at certain points It would seem that these roots originate in the gray matter above the point of origin and pass along the cord for some distance before passing out of the cord. In line with this it is found that by dividing the cord transversely in the cervical region there is produced a marked vascular change throughout the entire body. This seems to indicate that there is a

common point of origin in connection with all the vaso-motor fibres either in the medulla or higher up. According to other physiologists, while this represents the main center the other vaso-motor centers are distributed throughout the spinal cord. Both classes of physiologists are agreed in this that the chief centers of reflex action in connection with vasculation are found within the cerebro-spinal system from which the distribution of the nerve fibres takes place. The chief vaso-motor centers are found in the medulla, the subordinate centers being found in the spinal cord, at least the upper part of the lumbar region. All the vaso-motor fibres are supposed to originate in the medulla and in the spinal cord. The vasomotor fibres pass along the lateral columns of the cord and away from the cord in the anterior roots of the spinal nerves at least as far down as the second lumbar. The most important physiological functions of the vaso-motor nerves are reflex in their character, in connection with afferent and efferent nerve fibres. Brown-Sequard found that by punching the skin on one side there was a lessening of the temperature in the corresponding member on the opposite side. This indicates that the effect was produced by reflex action.

We find certain nerve cells which in combination preside over the nutrition of nerve fibres. Pathological observations seem to indicate that progressive muscular atrophy is associated with certain lesions found in the cells in the spinal cord. By the division of the sympathetic nerve there is found to be an excessive increase of the nutritive process in particular parts and sometimes inflammation. There may be found progressive muscular atrophy without any paralysis except in connection with the enfeebling of the muscles due to the partial destruction of the muscle contractility. Constantly accompanying these changes in the muscular tissue there is found to be the destruction or degeneration of certain cells in the antero-lateral columns of the cord and at the same time an atrophic condition of the corresponding anterior roots. This seems to indicate that there are certain cells in the spinal cord different the ordinary sensory and motor cells which may be characterized as atrophic cells. Against this it is claimed that the cells in the antero-lateral columns are associated with motion, the impulses originating in these cells passing to the muscles along the anterior roots. It is certainly known that if a muscle is cut off from motor influence for a length of time the motor fibres become atrophied and the muscles lose their contractility. If there is a destruction or degeneration of some of these motor cells in the spinal cord this condition of muscular atrophy may be due to such a lesion. It is certain that the degeneration of these motor cells in close connection with the anterior roots would give rise to degeneration of the anterior roots. From this it is assumed that there is no necessity for the existence of special trophic cells. If some of the motor cells are diseased and if the degeneration process is going on gradually there would be progressive paralysis in the muscles. On this basis progressive muscular atrophy is explained without recourse to special trophic centers. This does not finally settle the question of the existence of such trophic centers or nerves, especially as it is found that there exist certain tissue variations in the case of progressive muscular atrophy which are difficult to explain without assuming the existence of special centers and nerves.

The question of whether the sympathetic system is in a sense independent of the cerebro-spinal system or whether it is dependent upon the cerebro-spinal system is one that remains as yet unsettled. According to

Waller the sympathetic nerves are subject to spinal control. He cites four reasons for this opinion; (1) the fact that the motor fibres in connection with the iris originate in the cerebro-spinal system; (2) the fact that the vaso-motor fibres also originate in the cerebro-spinal system; (3) the fact that the medullated fibres which are considered vaso-motor can be traced from the spinal cord to the sympathetic system; and (4) that no reflex functions have as yet been associated directly with the sympathetic system. There remains, however the evidence that we pointed out before of a certain independent action on the part of the sympathetic system which seems to indicate that while normally the sympathetic system is under cerebro-spinal control, it is capable in a certain degree of independent action.

CHAPTER XII. THE SPECIAL SENSES.

SECTION I. Introduction.

The senses represent an external organ upon which an impression is made; this impression when conveyed to the sensorium becomes the basis of a psychic preception. Preception and the reproduction mentally of an image of the impression represent the psychic side of the special senses and these will be discussed is connection with psychology. Sensory impressions have been usually divided into five classes; (1) visual, (2) auditory, (3) olfactory, (4) gustatory, (5) tactile and muscular impressions. To these we must add locomotive impressions to be discussed in connection with animal mechamics, In all these senses there are three factors; (1) external stimulation in connection with some special organ that has eonnection with the nerve of special sense; (2) this impression must be transmitted along a nerve as an impulse; and (3) the impulse is received in a center or centers resulting in the consciousness of an impression or a sensation which from the psychic side forms one element in the representation of sense necessary to psychic preception. This implies the existence of sense organs, nerve paths of sensory impulses and a center. Hence the necessary conditions are a terminal mechanism, a conducting medium or nerve and a center or ganglion or brain for the reception of impressions. The impulse is passed from the organ to the center along the nerves of special sensation, these nerves being specialized in function in connection with the action of the mind, as the mind interprets the sensations. According to this the stimulation of the nerves of special sense produces sensations of a particular kind and this forms the basis of the principle of specific energy, in the case of the sensory nerves. For example, the stimulation of the optic nerve may take place in different ways, by different stimulants but so soon as the impression arrives at the brain it produces a light sensation or a color sensation. This does not imply that each special nerve fibre is different in structure but that the action of the excitant in connection with the center produces the special result. There is also a difference based upon the terminal organ, the terminal organ being so differentiated as to be capable of receiving only certain kinds of impressions, so that each terminal organ is specially adapted to receive special stimuli. The sensory impression does not pass directly to the psychic centers. The impression is received in the localized reception center, this center having the power of transmitting or not transmitting those impressions to the center of preception.

In connection with sight we find the best example of this, where we find the corpora quadrigemina lying between the psychic centers and the optic region and tracts. In these optic tracts impressions are recevied and when coordinated in the corpora quadrigemina they may be transmitted to the higher centers. These corpora quadrigemina are supposed to have the power of storing up impressions and also the power of blending together a number of impulses so that these impulses may be sent up to the higher centers, without any direct external stimulation or without corresponding to the single impressions. In this way impressions may continue latent for a considerable time and afterwards may be aroused in the receptive and coordinating centers and then sent up to the perceptive center. These intermediate centers no doubt perform the function of uniting the sense organs with the higher centers and also with the centers of motivity. There is time necessary for the transmission of such impressions after their reception. The excitation stimulates the cutaneous or peripheral structures. The impulse travels along the sensory nerves, is communicated to the brain and there distributed, resulting in sensation followed by perception. After this volition is called into play with the result that an impulse starting in the brain passes along the motor fibres to the muscles of movement or locomotion. The time occupied in this transmission includes both the physical and the psychical processes. There is a difference among the sense organs as to the number of stimulations they can receive in a second, each separate stimulus producing a sensation. The period that elapses between the stimulation of the sense organ and the resulting motion is called the reaction time. When there is involved in this a discriminating of objects perceived there is an additional time required; the time required for the discrimination of a color or for localizing the spatial field is called the perception time. When there is stimulation of the sense organs this stimulation is produced by some form of movement, light being the vibration of ether, sound the vibration of air and touch representing changes of pressure due to varying oscillations. Thus the action of the normal stimulation depends upon the character of the wave movement, its length, its amplitude and its form. In connection with these wave movements the wave length determines the number of waves in a given time, the amplitude determines the intensity of the impression and the wave form the quality of the sensation. Weber has formulated a law bearing upon the intensity of the stimulus, if the strength of the stimilus increases in geometrical proportion the staength of the sensation increases in arithmetical progression. This means that the intensity of the sensation depends on two things, (1) the intensity of the stimulation, and (2) the degree of irritability in the terminal organ affected at the time of the stimulation. The intensity of a sensation is found not to increase in proportion to the intensity of the stimulation. The stimulus may be a maximum or a minimum or a constant ratio between the intensity of the stimulus and the intensity of the sensation. By altering the stimulus and observing the variation in the sensation it is found that there is no constant ratio between these. Different sense impressions vary and the different sensations produced in connection with them also vary in quality, this difference depending largely on the variations in the vibrations of the air; for example, the lowest musical note is produced by fifteen vibrations per second, while the sensation of the red color in connection with the spectrum represents a vibration of 450 billions per second. These sensory

impressions on reaching the brain become sensations and if the mind refers this sensation to something external producing it as a cause then we have an idea. The connecting link between the sensation and the idea is called the perception. The relation of these to each other and to the mind will be discussed in psychology. In the senses taken as a whole we find two divisions, (1) those resulting from delicate movements of vibration on the basis of molecular action or chemical variation, as in vision, taste and smell; and (2) those resulting from changes in connection with the mechanical elements of contact or pressure in relation to the external organ of sense, such as we find in audition and the tactile and muscular sensations. There are some general sensations such as those of feeling, pain, hunger, etc. but these may be taken to refer to conditions that are found associated with the body in itself rather than with the body in its relation to the external world. The function of the sense organs may be said to be that of communicating to the sensorium impressions made upon these organs by external objects so that they represent media of sensory perceptions. In addition to the existence of an end organ, the presence of a stimulus specific in its nature, the connection of the sense organ with the cerebrum there must be psychic attention during the process of stimulation in order that the sensation may be referred to some external cause. In connection with the stimuli which are brought to bear upon the sense organ these must be adequate, in other words, adapted to the organ in connection with which stimulation takes place. Many other stimuli are found which do not produce the normal sensory perception but which act upon the nerve elements and produce certain results, as for example, mechanical, electrical or thermal stimuli which when acting on the organs produce changes. Stimuli that act upon sensory organs which are adequate must act within the limits of strength and hence there is a limit to the intensity of the stimulus both maximal and minimal. When a sensation continues after the stimulus producing it has been removed there is said to be an after sensation; when stimulation takes place without the excitation of the external organ of sense by some internal cause the sensation is called subjective. When the subjective sensations become characteristically cerebral they are called hallucinations. In connection with the special senses all our knowledge of the external world comes to us and the character of our knowledge of the external world depends upon the perfect and intact condition of these senses. In addition to the old classification of the five senses there are at least two other senses which require to be taken account of, those of temperature and pressure; according to others there are purely muscular senses and sensations associated with localization and locomotion. In the end organs of the special senses we find modified epiblastic cells, the modification taking place in the development of the body organism and the special organs in relation to the body. The different senses occupy areas that vary considerably, the visual area being about 20 sq. cm., the auditory area about 5 sq.cm., the olfactory area about 10 sq. cm., and the gustatory area about 50 sq. cm., while the tactile and pressure sensations are associated with an area extending over the larger part of the body surface. Even in the special senses, however, there is not an absolute limitation to a small area, as for example in the sense of taste which is distributed over the tongue and palate and the sense of smell over the mucous membrane of the nasal passages. There is, however, a distinct localization of the sensory area in connection with vision and audition.

SECTION 11. The Sense of Vision.

The eye as the organ of vision represents a spherical organ consisting of transparent portions one situated behind the other encased in membranous structures. The transparent portions consist of the aqueous humor, the chystaline lens and the vitreous humor or semi-fluid substance which is encased within the hyaloid membrane. In the lens we find a number of layers consisting of fibres, the density of which increases from the margin to the center. Surrounding these three transparent portions are three membranous layers, the external layer consisting of an anterior cornea and a posterior sclerotic; the choroid membrane consisting of the choroid proper which covers the interior portion of the sclerotic and the interior portion of which constitutes the iris and the ciliary processes; in addition to these we have the retina which covers the posterior portion of the eyeball between the vitreous humor and the choroid. The retina represents the part of the eye that is particularly sensitive to the light. In order however that a ray of light may reach the retina it must pass from the anterior to the posterior through a number of transparent structures, the cornea, the aqueous humor, the crystaline lens and the vitreous humor. The external coating consists of the anterior cornea and the posterior sclerotic, the sclerotic being formed by bundles of connective tissue mixed with elastic fibres and forming a network. The choroid is found in two layers, a superficial which contains the arterial and venous ramifications found imbedded in a substance of elastic fibres and pigment corpuscles together with connective tissue fibres and smooth muscle fibres; the deeper layer consists of a meshwork of capillaries in the midst of which we find no characteristic element. Between these two strata we find a delicate layer of elastic fibres which is called the boundry layer of the ground substance. The retina which represents the terminal organ of vision reaches from the point where the optic nerve enters to the iris margin. The retina consists of three parts, one in which the optic nerves terminate, the sensitive part to light; a second part extending to the ciliary margin of the iris; and a third part which covers over the posterior iris surface to the edge of the pupil. The layer of nerve fibres forms a plexus in connection with the axis cylinders of the nerve fibres. The layer of ganglion cells is found to consist of multipolar cells sending out axis cylinders to the nerve fibre layer and a few processes to the inner reticular layer which consists of a delicate network of sustentacular tissue. In the neuro-muscular part of the retina we find two different elements, the rods and cones which have their nucleus in the internal part of the cells, the external part having no nucleus. This layer is separated from the internal parts of the retina by a perforating membrane; the outer granular layer is found to consist of cells which are associated with the rods and cones, the difference being however that the nucleus is in the part of the cell which constitutes the outer granule. In connection with the rods the external part represents an elongated cylinder, the internal part or rod fibre consisting of a delicate fibre with a protuberance containing a nucleus. In connection with cones the outer part of the cone consists of an external segment which is conical and an internal segment which is oval in shape. The fibres of the cone are broad, resting upon the external reticular layer and containing an enlargement which has a nucleus. There are fewer

cones than rods; the cones are found at regular intervals while between the two cones there are always found a number of rods, usually three or four. The retinal elements seem to be all connected together, the ganglion cells being connected with the axis cylinders of the optic fibres; on account of the fact that there are a great many more fibres than cells there must be other connections, possibly the fibres being associated with different processes from the ganglion cells. It is probable that the rods and cones are directly connected with the fibres in connection with the outer reticular layer. The rods and cones represent the part of the eye retina that is sensitive to the light. The optic nerve represents the nerve that is associated with the sense of vision. The bundles of fibres represent delicate medullated fibres without the white substance of Schwann connected together by means of neuroglia. The lens consists of a substance which is covered over anteriorly with epithelium. The lens substance consists of a soft substance surrounding the nucleus and consisting of epithelial cells so elongated as to form lens fibres, these fibres representing prismatic bands which are thick at the posterior end. The vitreous humor represents a fluid substance in the midst of which fibres pass the external surface being surrounded by the hyaloid membrane. From the anterior part of the hyaloid membrane fine fibres are found to pass in the direction of the lens. These fibres constitute a membrane known as the zonule of Zinn.'

The sense of vision is usually aroused by the action of the light upon the retina. Any stimulation of the optic nerve however will produce a sensation, such as pressure or an electric stimulation. The normal stimulation however is the light. Light itself has no power actually to stimulate the optic nerve. It can do so only when it acts on the nerve through the retinal rods and cones. In front of the retina are a number of curved surfaces and various media by which the rays of light from any luminous point as they enter the eyeball are refracted or bent so as to be brought to a focus in the retina. Hence when an object is looked at there is formed a picture of it. The retinal image is always as regards the object looked at inverted. When properly focussed it is well defined and its size depends upon the visual angle. The refractory apparatus consists of the anterior surfaces of the cornea, the anterior and posterior surfaces of the crystaline lens, the substance of the lens and the aqueous and vitreous humors. The rods and cones are portions of the retina sensitive to light There has not yet been established a direct nerve fibre connection with these although such a connection is probable. There is undoubtedly a union between the ganglion cells and the axis cylinder of the nerve fibres. The nerve cells however as we have seen are not nearly so numerous as the nerve fibres, hence the fibres must have a connection in other ways. The optic nerve within the cavity of the eyeball is bound up in sheaths, these sheaths containing the brain membranes. The fibres when found in bundles are medullated without however the Schwann sheath.

A sensation of light is dependent upon either a sensation of the optic nerve or of the retina. The usual stimulus is light but artificial stimuli, such as mechanical pressure, division of the nerve or electric shocks may also act as stimuli. Light from a physical standpoint is a vibration which is found in the ether that fills all space. These vibrations affect the retina, producing molecular changes which stimulate the fibres of the optic nerve. This impulse is transmitted to the brain resulting in light

sensation. Physically light is to be regarded as a kind of movement; physiologically light is a stimulus that produces sensations, its action upon the organic elements of the special senses resulting in the special form of conscious sensations called the light sensation. These vibratory movements as they are found external to the organism have been studied carefully in physical science; but physiology has been unable as yet to study the results of these movements in the complex body organism because consciousness only takes account of the result. The sensations of light depend upon the phenomena associated with light. When there is a disturbance of the surrounding ether by luminous bodies an impression is made upon the retina resulting in a light sensation. This vibration or disturbance is originated from the luminous body and travels almost instantaneously in all directions with a great velocity. If these vibrations are intercepted by a dark sheet in which there is a small opening, the vibrations of light will penetrate this opening, moving in a direct line so that the light moves in a straight line. Hence the movement of light in its propagation from the luminous body is said to be rectilinear. Every ray of light consists of an indefinite number of minute rays moving in a straight line unless intercepted in some way. If the light thus moving rests upon a smooth surface either a part or a whole of each beam of light changes its movement by reflection, the light reflected moving in a direct line perpendicular to the surface of reflection. The two rays of light the one received and the one reflected forming equal angles with the surface of reflection. If the media on the two sides of the surface on which the ray of light falls are transferred then part of the light becomes refracted, that is, it bends at the surface where it passes into the second media, so that the light refracted lies in the same plane with that of the original light ray. The media of refraction may be glass, water, air or diamond. The course of the ray in its movement is a matter of mechanical calculation, depending upon the knowledge of the principal points in connection with the generated ray of light.

According to Listing the pathway of a ray when refracted may be determined in connection with our knowledge of three pairs of cardinal points. (1) A pair of principal points which have the characteristic that each point in the one principal plane has its image when the refraction takes place at a point in the other principal plane, at equal distances from the axis. In this way a figrue in the one plane has its image in the other plane and the position of the figure and image is identical in the two planes. (2) A pair of focal points, whose characteristic is that a ray from the first focal point when it passes through refraction becomes parallel to the axis and when a ray is parallel to the axis before being refracted when refraction takes place it passes through the second focal point. (3) A pair of nodal points whose characteristic is that each ray whose direction before being refracted passes through the first nodal point when refraction takes place it passes in a parallel direction through the second nodal point. In the eye we find four refracting surfaces, the anterior and the posterior cornea surfaces and the anterior and posterior surfaces of the lens. As the cornea surfaces are almost parallel and as the refraction index of the cornea does not differ much from the index of refraction of the aqueous humor the posterior surface may be omitted. In the case of the lens we find varying degrees of density, the density being increased towards the center. From this standpoint the eye is an optical instrument possessing the power of refraction through a trans-

parent medium. The eye is thus an optical apparatus consisting of a reflecting surface and a lens, the lens in this case being complex in character. When an object is placed before the eye an inverted image falls upon the retina the refraction through the transparent media producing the different points of the image.

While the eye is symmetrical as an optical instrument it is defective but the defects as a rule are so slight and we become so accustomed to them that they do not cause any errors in visual judgments. These defects are (1) due to aberration of refrangibility. This is due to the fact that the different rays of which white light is composed are unequally refrangible; hence in a ray of white light falling upon a convex lens the violet rays are more strongly bent than the red rays and are therefore brought to a focus in front of the red rays resulting in the reproduction and fixing of the color. The term chromatic aberration is used to designate this sam e defect of vision. This means that rays of light of different colors differ in refrangibility, so that the white light is separated into its component colors when it passes through a prism. The result of this is that the rays of one color are focused at a differdnt point from that representing the focus of the rays of another color. In other words an image consists of a number of images representing different colors. The existence in the eyeball of different refracting media of various densities tends to correct this defect. This means that if there is perfect accommodation of the eye for one color there is not perfect accommodation for the other colors. Normally in vision this effect of the different refrangibilities of different colors does not affect vision; but it can be discovered easily if we look at a violet light in which are rays from the two extremes of the spectrum, the eye will see either a small blue point with a red surrounding or a red point with a blue surrounding, according as the eye is accommodated to the red or the blue rays of light. (2) These defects may be due also to refractive curvatures of the refractive surfaces of which we find two varieties, (a) spherical aberration. The aberration of sphericity is due to the fact that when rays of light fall on a convex lens those which fall on the outer or marginal part are more strongly bent than those which fall near the central part of the lens; as a consequence the rays on the marginal end will be brought to a focus in front of the rays near the center. Hence in the eyeball the whole of the rays of light are brought to a focus exactly on the retina and so the image formed is more or less blurred, there is formed a circle of diffusion increasing according to the extent to which the pupil is opened. If the pupil is quite open then the vision is more marred. There are in the eyeball certain arrangements, the object of which is to diminish this defect as far as possible, as follows; the iris acting as a iaphragm cuts off the outer rays so preventing them from entering the marginal part of the lens by which they would be more strongly refracted: the anterior surface of the cornea is not perfectly spherical but the marginal portion is less convex than the centrai portion; the anterior and the posterior surfaces of the lens to some extent correct each other, the lens substance is more dense towards the center, hence the circumferential portion being less dense it is less refractive than the central part. (b) Astigmatism, by this is meant that a vertical and a horizontal line at the same distance from the eye cannot be seen plainly at the same time. This is due in the main to the fact that the vertical curvature of the cornea is more convex than the horizontal, hence the rays that fall on the former are more strongly refractive and

are brought to a focus in front of those that fall on the latter. There is not symmetry in the refracting surfaces, so that in place of the circles of diffusion we find figures or lines irregularly shaped. Astigmatism is usually divided into a regular and an irregular form; the former representing the difference in the curvature between the horizontal median line and the vertical median line so that the eye lacks the power of accommodating the two rays representing the vertical and horizontal. In this case both lines cannot be seen at the same time, generally the vertical median line is more curved than the horizontal. This defect may be corrected by the use of plain cylindrical glasses, as they increase the refraction of the rays in the horizontal media until there is a common focus for the horizontal and the vertical. In irregular astigmatism there is an irregular variation in the curvature in different median lines, this being due chiefly to the variation in the crystalline lens. In order to have clear vision the image must fall on the retina. If the eye is adjusted so as to see a certain object, the rays coming from a point further away will be focussed before reaching the retina, a divergence from the focus of the retina being represented by a circle of diffusion; the same thing will be true of a point nearer the eye. By sighting these different points the circles of diffusion are formed and when the centers of these circles coincide the sighting is accomplished. There is a line of sighting in these cases which is formed by the axis of the conical sides of the rays from the two points, the arginal border of the iris forming the boundary line.

In order to find the cardinal points of the eye we must measure the refracting media and find the refraction indices. Some investigations have been made in connection with this subject. In connection with the postmortem eye and also in the case of the living eye these investigations have been carried out. By means of these measurements we are able to determine the optical constants associated with the different parts of the eye in connection with vision. In the case of a luminous object before the eyes the rays from the surface cross in the eye, forming an inverted image in the retina. The angle at which the rays from the marginal surface cross is called the visual angle, its size depending upon the size of the object as well as the intervening space between the object and the eye. Objects of the same size at different distances may have the same visual angle. In this way the size of the retinal image may be calculated if we know the object and its size. If small opaque substances are found in the transparent media there may be a shadow cast upon the retina, giving rise to images which may be supposed to be real as existing in the outer world, while their existence is really in connection with the media of sight. These are called entoptic objects as distinguished from the external objects of vision. These entoptic objects may be of two kinds; (1) intraretinal, arising from opacity in the retinal layers anterior to Jacob's membrane, representing the layer of rods and cones of the retina. This may be produced artificially by casting a strong ray of light on the border of the sclerotic by which a figure of the retinal vessels will be produced; it may also be produced by looking at a vivid light through a small hole before which quick back and forward movements takes place. In this case also the retinal vessels will be reproduced in image. By looking at a very bright light through a tube while the head is moved backward and forward the circulation of the blood in connection with the eye and even the blood cor-

puscles may be seen in the form of a picture. In this way we find that the sensitive portion of the retina is found in connection with the layer of rods and cones. (2) The object may be extra-retinal, due to some opacity in some of the refractive structures in front of the retina. These objects may be seen in various forms and shapes according to the structure of the substance or the substance itself, the appearance being that of objects moving too and fro before the eye. These facts seem to indicate that the most sensitive part of the retina is the deepest of the layers, the layer of the rods and cones. We have seen that in order to see objects clearly the light reflected from them must be accurately focussed upon the retina; but as at different times we see clearly objects at different distances there must be in the eyeball some arrangement by which focussing power can be altered, for the nearer an object is to the eyeball the greater the divergence of the rays which enter the eye. Therefore the greater the amount of refracting or bending will be required to bring them to a focus on the retina. Hence to see near objects clearly we require greater refraction power than to see distant objects clearly. If a camera is placed in front of an object it requires to be focussed in order to get a distinct image on the plate. The focus of objects at different distances is obtained by the alteration of the position of the plate relative to the refractory lens, moving the plate forward when focussing distant and backward when focussing nearer objects. In the eye there is a natural mechanism for such an accommodation. This is accomplished by changing the refractory power of the refractory apparatus, increasing it when looking at distant objects. There is one compound gland in the eye composed of different media of refraction the focal length being definite. There may be a difference between the focal length and the antero-posterior axis of the eyeball In the case of the normal emmetropic eye the refracting apparatus is such that the rays of light originating beyond a definite point, 65 meters distant, and which are parallel to each other, are brought to a focus on the retina. When the antero-posterior axis is of such a length that the two focal points in connection with the refractive media fall npon the retina there will be focussed on the retina parallel rays of light emanating from objects at a distance. This represents the emmetropic eye. If this axis of the eye is longer or shorter than the focal measure of the length of the refractive media than it is out of measure and the eye is said to be a metropic. From lumiuous points within a distance of 65 meters, more or less divergent rays of light fall upon the eyeball and therefore refracting power is required to bring these to a focus upon the retina, that is accommodation is necessary. In the chief change is an increase in the convexity of the anterior surface. There is also a contraction of the pupil and an increase of the intra-ocular pressure in the posterior parts of the eye. Accommodation. The increase of the convexity of the anterior surface of the lens appears to be due to the contraction of the ciliary muscles which by their contraction pull off the ciliary processes from the suspensory ligament. When the latter is no longer pressed upon the capsule of the lens will be diminished. Hence the lens by its elasticity bulges forward or becomes convex anteriorly. The nearer an object is to the eyeball the greater is the amount of refracting power that is necessary, that is, a greater increase in the convexity of the lens is needed to bring it to a focus on the retina. When an object is placed nearer the eye than 13 cm. cannot be accommodated for it too

near. The rays of light passing from it are too divergent to be sufficiently bent to bring them to a focus on the retina. Hence a normal emmetropic eye has an accommodation that takes place between 13 cm. and 65 meters the points represented by these distances being called punctum proximum and punctum remotum.

From the normal emmetropic there are two divergences falling under the head of ametropic; (1) the myopic or short shighted eye. In this case the axis is too long. The ordinary myopic eye of short sinhted people has in the curvature of the refractory surfaces too much convexity, or the antero-posterior axis of the eye is too long. Hence the rays of light from a distance are formed in front of the retina and concave glasses are needed to correct the vision. This form of sight is called myopic because persons with such sight lessen the circles of diffusion of light by partially closing the lids. (2) The hypermetropic or long sighted eye. In long-sighted people we find either the curvatures of the surfaces are not sufficiently convex or the antero-posterior axis is too short. Hence when the rays of light from a distance are brought to a focus behind the retina, accommodation is always necessary and convex glasses are required to correct the vision. In the case of the presbyopic eye of old people we find an eye in which the power of accommodation has become defective in consequence of the weakening of the ciliary muscles, flattened and diminished elasticity of the lens. The person as a consequence cannot distinctly see an object unless it is held at some distance from the eye; weak convex glasses should be used to correct this defect. If the two eyes have equal refractive power they are said to be isometropic, if different they are called anisometropic. If a convex lens converging parallel rays of light is put in front of a hypermetropic eye the focal point can be removed so as to center it on the retina. Similarly if a concave lens is placed before a myopic eye the focal point will be moved back until it rests on the retina. In both of these cases clear vision will be restored. The number of lenses required to accomplish this gives the basis for the rectification of defective sight. The opticans use a metric scale in which the unit is a lens of one meter focal distance to which the name dioptric is given. This is called number one. The next, number two would be one-half the focal length and the lens double the power of number one and so on. In the normal eye the parallel rays of light entering it from a distance are focussed on the retina; if these rays are not focussed properly on the retina there are formed circles of diffusion and there is an indistinct retinal image. Thus if an object is too close to the eye the refractive media do not permit its focussing, with the result that there is indistinctness of vision.

This however is corrected by accommodation which takes place by varying the curvature of the anterior surface of the lens. By the use of the phakoscope experiments can be made in connection with the variations that take place in the accommodation. It consists of a triangular box with three angles squared off. To the right of the figure there are two prisms by means of which light is concentrated upon the eye. The eye is placed before an opening on the side opposite to the square side while the observer's eye is located at the left angle. In connection with accommodation we find variations taking place, (1) there is an increase in the curvature of the anterior surface of the lens; (2) ordinarily there is contraction of the pupil of the eye; and (3) there is an increase in the intraocular pressure in the posterior portion of the eye.

According to Helmholtz the explanation of the increase in the curva-

ture of the anterior surface of the lens is as follows. In the normal condition the lens is flattened anteriorly by the anterior layers of the capsule. When accommodation takes place the ciliary muscle fibres pull forward the ciliary processes and the retina with the result that the lens is bulged forward and becomes thicker. During the resting condition of the eye the zonule of Zinn is subject to some tension. But in the action of the ciliary muscle there is a pulling force towards the edge of the cornea, the ora serrata or serrated border of the retina being drawn towards the corneal margin, lessening the radial tension of the zonule. The ciliary muscle receives motor fibres from the ciliary ganglia, these arising from the third nerve so that if the third nerve is paralyzed there is no longer any power of accommodation in connection with the eye. The light entering the eye is partly absorbed by the choroid pigment and in part it is reflected. The rays that are reflected return to the pupil uniting with the entering rays to form a picture. The eye pupil is black when looked at because none of the reflected rays are received into the observing eye. If the retina is strongly illumined with light and if you place a lens in front of it so as to focus the rays in the observing eye a picture of the retina may be observed. It is on this principle that Helmholtz's ophthalmoscope is constructed. When there is a deficiency of pigment found in connection with the eye it appears luminous producing reflection of the rays of a red or pink color. If there is set in front of the eye a dark sheet with a hole of equal size as the pupil of the eye the hole would appear to be dark instead of light. In some animals part of the eyeball base has no pigment and for this reason it manifests irridescence. When this condition is found, that is, where the pigment is absent as in the case of some animals it is called tapetum, the eye being in this case more sensitive to the rays of light. This tapetum is always higher than the entrance point of the optic nerve. In some animals it is of a bluish color due to irsidescence produced by the interruption of the light wave. This tapetum represents the bright colored reflecting layer of the choroid, the light penetrating these layers and then being reflected from a delicate surface. When an image is reflected on the retinal surface it is reflected upon the are of a spherical surface. The eye in this respect is more nearly perfect than a camera in which the surface is flat. This forms a reason why in a camera picture of a large object the outside of the picture is less fully developed than the central part because the outside surfaces are not in focus. Sometimes these external parts become distorted. In the case of the eye as the rays fall on the concave surface all the rays of light are focused so that the image becomes quite distinct.

In the correction of the defects associated with the eye the iris represents the most important part of the eye. The iris acts as a diaphragm which prevents the rays of light from falling on the outer or marginal part of the lens by which the rays would be so strongly refracted that they would be brought to a focus in front of the retina. (1) The iris thus prevents the formation of a blurred image and this represents the first function of the iris. (2) By the contraction and relaxation of its muscular fibres it determines the size of the pupil and so regulates the amount of light entering the eye. The radiating fibres contract, producing a dilatation of the pupil, whereas another system of radiating fibres on contraction produces a lessening of the pupil. The contraction of the pupil is due to the contraction of the circular muscular fibres of the iris, these being supplied by the third cranial nerve. The dilatation of the pupil is due

to the contraction of the radiating involuntary muscle fibres, these being supplied by the sympathetic nerve fibres which can be traced to the sympathetic system in the lower cervical and upper dorsal regions. (3) By the contraction of the circular muscle there is an accommodation for near objects as it cuts off the more divergent rays from the aperture of the pupil. The diameter variations in the pupil depend upon the intensity of the light falling upon the retina. If the light is strong the pupil contracts; if the light is less intense the pupil dilates. If the light is strong and acts strongly upon one eye only it will produce contraction of the pupil of both eyes. These indications point to reflex action as the cause of the phenomena of sighg, the optic nerve being the sensory pathway to the center in the brain from which impulses pass out along the motor fibres to the pupil of the eye. By the stimulation of the optic nerve the pupil contracts. It is said that the center is in the corpora quadrigemina because if these bodies are destroyedthe pupil of the eye loses its mobility; the dilator fibres spring from the sympathetic arising from the lower portion of the cervical region and the upper part of the dorsal region. Aside from nervous connection the iris seems to have the power of responding directly to the stimulation of rays of light. In the case of a dead animal the pupil of the eye will contract if the light is allowed to fall upon it for a long time. If however the opposite eye is covered no response to the light stimulation will be apparent in the eye that is unclosed. The pupil of the eye contracts under the influence of light and this is a reflex action. The afferent nerve is the optic, the center is in the corpora quadrigemina in the floor of the aqueductus Sylvius, the efferent nerve being the third cranial. Both pupils contract when strong light acts upon one retina only. The pupil of the eye also contracts in accommodation for near objects, when the eyeball is turned inwards, in deep slumber and under the influence of morphine and nicotine. The pupil of the eye dilates when the intensity of the light is diminished, when looking at distant objects and under the influence of strong sensory stimulation as well as when affected by atrophin and cocaine. In the case of the iris its main function seems to be to control the light falling upon the eye so as to make the image that is formed upon the retina quite distinct. This function it performs in two ways, (1) by lessening the rays of light reflected from objects close at, hand by taking awaythe divergent rays and permitting only the parallel rays to become focussed on the retina; (2) by preventing the divergent rays from being focussed in front of the retina, in this way obviating the condition of spherical aberration. In both of these ways the light entering the eye is regulated so as to permit only those rays to enter the eye that will be of value ni the formation of the retinal image. All the portions in the front of the retina are functionally arranged for the assistance of the eye in focusing an image.

Light is the normal stimulus of the retina, the retina being the end organ of vision, and all the parts anterior to it being arrangements associated with focusing an image. Stimulation may take place mechanically or electrically in the case of the optic nerve, not directly, but by acting upon the nerve firbe through or in connection with the rods and cones, especially the latter. Hence light passing through the various refractive media has to travel through the thickness of the retina in order to reach and affect the rods and cones situated on the posterior aspect of the retina. The changes that are thus produced have to travel forward through the optic nerve fibres that

lie in the anterior aspect of the retina. What the exact changes are that light produces in the retinal structure are uncertain. Several changes however have been observed, but how these lead to the stimulation of the optic nerve cannot at present be explained. When light falls on the retina there is a change in the electric current; this must be due to a change of a chemical or thermal character in connection with the retina. If an animal after being killed in the dark is brought into the light and the retina subjected to yellow rays of light, there will be found a purple color in connection with the retina; this purple color is destroyed if the retina is exposed to the ordinary light, the purple being decomposed by the ordinary light rays. The same purple color is found in the eye of the foetus before birth, the purple being found in the rods never in the cones. The light seems to affect the purple of the eye, the result produced being some mechanical change producing stimulation of the optic nerve. When the purple is used up new matter of the same kind is formed from the coloring matter of the epithelium, the epithelium secreting the coloring matter from the blood that circulates close to it. The retina then is a physiological sensitive plate. The coloring matter is destroyed and restored by chemical changes, the action of these chemical changes resulting in a vaaiation of an electrical kind. This purple coloring matter is not necessary for vision as the cones have no purple. There is in all probability however a colorless matter in connection with the cones which produces the necessary chemical changes. Thus when the eyeball has been kept for some time in the dark the hexagonal pigmented epithelial cells situated in contact with the rods and cones have their pigment mainly gathered in the dark into the body of each cell and from each cell we find short filamentous processes which project a short distance between the rods and the cones. Under the influence of light these processes become loaded with pigment and project between the rods and cones a much greater distance. The retina examined a short time after death is of a faint pink color, but if the animal is kept in the dark and then killed the retina except at the yellow spot is found to be of a purplish red color. This is due to the presence of the coloring matter to which the name of rhodopsin or visual purple is given. Rhodopsin is bleached by the white light. Hence in order to see it the retina must be examined by the sodium light. It is restored again in the dark and if the retina is brought into contact with the hexagonal cells. Hence it is supposed that the rhodopsin is formed in the outer part of the rods by the action of these cells. An electric current can be obtained from it, the current increasing with the light that falls on the retina. When the eye rests in the dark the coloring matter collects near the external portion of the rod close to the junction of the internal and external segments. When exposed to the white light diffusion takes place of the coloring matter over the rods inward. The white light in producing this diffusion elongates the rods. If the eyeball is pressed luminous impressions may be produced. These impressions take the form of a luminous point surrounded by colored rings. These may be large or small, depending upon the rays of light falling on the retina. If an electric current is passed along the optic nerve a little violet scintillation may be noticed surrounded by a dark yellow ring. If the edges of the retina are excited a violet spot may be noticed if the current is passed from the optic nerve to the retina. Even when the eye is in a dark medium there is not absolute darkness, there being a slight luminous ray characteristic of the eye in the darkness

this being called the specific light of the retina. It appears from this that even in the darkness there is an activity of the molecules which produce the luminous sensation. The retina is not excitable to an equal degree in all its parts. At the point of entrance of the optic nerve there is no lighi sensibility, this point on the retina being called the blind spot. By shutting the left eye and fixing the right eye on a cross which is about an inch to the left of a round dark spot on a white surface and then moving the surface towards and away from the eye there will be found a position where the round spot entirely disappears, the image resting upon the point of entrance of the optic nerve. At this point there is no sensibility of color.

The most sensitive point of the retina is the yellow spot at the center of the retina. It is especially used in direct vision. If the eye is fixed on a word in a certain line the rest of the line becomes indistinct. This is particularly true of the fovea centralis where there are only the retinal cones representing a small area about .2 millimeters in diameter. Acute vision becomes gradually less acute on passing away from the yellow spot. The retina is most sensitive after it has been resting, for example, in the morning. It remains excited for a short time after a stimulus has ceased to act on it. Thus a colored spot on a rapidly revolving object disappears as a continuous band because the excitement of the first stimulus upon the spot has not ceased before the spot comes around again. In order to excite the retina if the stimulus is weak it must continue for a definite time, if strong it may be of much shorter duration. An electric spark lasts only about .000001 of a second yet the spark is sufficiently strong and extended to make a light impression. When there is rotation of an object or color so as to produce a fusion of the successive impressions we have the persistency of retinal inpressions. Normally an impression continues on the retina about one-fiftieth of a second. This persistency of excitement after the stimuli have ceased to act explains the positive after image, while the negative after image where light parts of the image correspond to dark parts of the objects seen and vice versa is due to the fatigue of the retina. An after image is the picture of an object that can be seen after looking at the object for a time and then closing the eyes or looking at a dark surface. In order to excite the retina there must be a definite intensity of light, this intensity of light stimulation depending not only on the luminous body but also on the excitability of the retina. Hence after rest or after being in the dark there is an increase in the retinal excitability.

Light and color.—Light is due to the oscillations of the ether. This is a hypothetical substance supposed to fill all space and to occupy the space between all material substances. The color or tone of light depends upon and varies with the length of the ether waves. Color is a sensation aroused by the action of rays of light of a certain length upon the retina, that is, it depends upon the rays that fall upon the retina during a definite period of time. With a certain number of rays we get a sensation of red and with double that number of rays the sensation would be that of violet. The brilliancy or intensity of light varies with the amplitude of the waves. If a beam of light is made to travel through a glass prism the light is not only reflected but it is broken up into several primitive colors from red at one end of the spectrum to violet at the other end. These when collected on a screen are seen to form the spectrum. Thus white light is of a compound nature, the waves of red light are of such a length

that 451 billions of them reach a given point in one second of time while the waves that produce a violet are much shorter, 764 billions reaching a given point in one second of time. The waves of intermediate length form the other colors of the spectrum. Color is thus a sensation due to a particular kind of stimulus. If the waves are longer than the red waves they do not stimulate the retina and instead of forming light or color rays they are heat rays. Simlarly waves that are shorter than the violet rays do not excite the retina and they are chemical rays called ultra-violet. By examining the spectrum we get a series of colors the one merging into the other as follows; red, orange, yellow, green, blue, indigo, and violet. These are the primitive colors. If two or more of these primitive rays act on the same part of the retina we have the mixed color sensations. There are two kinds of these mixed colors, (1) those existing in the spectrum, and (2) those that do not correspond with the spectrum colors. Two colors which mixed together give the sensation of white are said to be complementary to each other, for example, red and greenish blue, violet and greenish yellow, orange and cyanic blue. If white light rests upon a surface all the rays may be absorbed except the red. If the red rays are reflected then the color sensation is red. If the blue rays are reflected then the color sensation is blue. If we look through colored glass all the rays are absorbed except the glass color and thus the object seen through the colored glass seems to be of the color of the glass.

In the case of all the separate colors we find that they possess three characteristics; (1) they have a definite tone due to the number of vibrations per second; (2) they possess a definite intensity due to the degree of the vibration. It is thus that we have the variation in the color sensation from a bright color to a dark color. (3) They are all definitely saturated depending upon the amount of white that is in the color. There is a perfect saturation when all white is absent as in the case of the primitive colors of the spectrum. We find historically different theories in regard to color perception. Young and Helmholtz have formulated an ingenious theory in regard to the perception of the different colors. This theory presupposes that there are in the retina three sets of nerve fibres, one set acted on strongly by the red waves, another set by the green waves and a third by the violet waves. Each cone is said to be connected with three of such nerve fibres. According to this the red, green and violet are supposed to be the primary sensations. If the light is homogeneous all these sensations are excited, but the intensity of the sensation depends upon the length of the waves. Long waves arouse the red fibres, moderate waves the green, and the short waves the violet, the other fibres being in each case feebly excited so that the sensations are respectively red green and violet. When both red and green fibres are strongly stimulated a sensation of yellow color is produced. A strong stimulation of green and violet fibres leads to the sensation of the blue color. When all the three kinds of the retinal nerve elements are equally stimulated a sensation of white light follows. Thus the yellow, blue and white are modified color sensations depending upon the blending of the primary color sensations. This theory seems to explain; (1) Daltonism or color blindness, for we may imagine a person who cannot appreciate the red color as one in whom the red retinal nerve elements are either absent or paralyzed. All eyes have some form of color sensation although the sensation for special colors map be absent. Color blindness exists to a large

extent among individuals, the most common color in which sensation is absent being the color of red. (2) This theory also accounts for the fact that negative retinal images are always of the color that is complementary to the color of the object looked at. Thus if the eye is fixed intently for some time on a red surface, the red nerve elements become exhausted, so that when the eye is turned on to a white surface these elements will not respond to the red rays in the white light. The green and the violet elements will however respond to the rays of the white light which affect them and so a bluish green color will be seen on the white surface. By keeping the eye in darkness the nerve elements stimulated by red become exhausted and these elements do not act so as to produce a red sensation. The green and violet elements have not been stimulated to excess with the result that the combination of these two by stimulation gives us a bluish green sensation. By fixing steadily the eyes on a white surface the red nerve elements become exhausted while the green and violet elements become more strongly stimulated. If the eye is steadily fixed on a bluish green surface there will be a stronger stimulation of the green and violet elements giving a very strong complementary color.

Hering proposes another theory of color perception. He claims that these color perceptions depend upon the different changes of a molecular character that take place in the retina. Hence he says that in the metabolism of the retina we have the anabolic processes associated with blue, green and black, representing the constructive processes of vision; while the katabolic processes are associated with yellow, red and white or the destructive processes of vision. Instead of the three pairs of colors being complementary, as in the Young-Helmholtz theory they are the opposites. Wundt has produced another theory according to which he claims that whenever the retina is stimulated by light there is a two-fold process taking place; (1) a chromatic process depending on the length of the waves and producing a tone in the case of color; (2) an achromatic process also depending on the length of the waves but connected with the intensity of the color. In the achromatic stimulation there is a maximum attained in the yellow, shading taking place along the varying spectrum colors towards the ends of the spectrum.

If we look at a small spot on a colored surface the spot being black or gray or white, the spot seems to be of the complementary color to the ground. For example, a gray point on a red surface seems to be greenish blue and on a blue surface the same point would be pink. These are presumed to be due rather to the visual judgment that to the visual sensation, so that it is a matter of visual perception. In the eyeball there is a point which is the center of rotation situated a little behind the center of the antero-posterior axis. Through this center passes the antero-posterior axis, also the vertical and transverse axes and around either one of these axes rotation may take place. To the eyeball there pass six muscles by the contraction of which the rotation of the eyeball around these axes is produced. Thus the eye is turned outward by the external rectus, inward by the internal rectus, upward by the combined action of the superior rectus and inferior oblique, and downward by the combined action of the inferior rectus and superior oblique. In looking at any object both eyes are fixed on the one point called the fixed or visual point and a line passing from the center of rotation of the eyeball is called the visual line. By the two visual lines converiging an angle is formed at the visual point. In regard to the movements of different kinds, we find

(1) movements, when the head is in an erect position the visual line is in the direction of the horizon. (2) Rotatory movements take place around the transverse and vertical axes. In the rotation of the eye around the transverse axis the visual line becomes displaced forming in connection with the original visual line an angle of vertical displacement. In the rotation of the eye around the vertical axis the visual line becomes displaced laterally, the angle of lateral displacement being formed in connection with the median plane. In addition to this we have the movements of the eyeball in rotation along with the vertical or lateral displacements. This rotatory movement is indicated by the angle formed between the transverse and visual planes, this angle being called the angle of rotation. According to Listing when the visual line changes from the primary position to a secondary position the torsion angle in the secondary position is the same as if the eye had moved into the secondary position in rotating around a fixed axis perpendicular to the first and second positions of the visual line. According to this the rotation of the eye is always in the equatorial plane of theeye, the eye rotation never being found around the antero-posterior axis. Normally the two eyes move symmetrically so that the visual lines are directed towards the same point in space; although when looking at anyobject with both eyes an image is produced on each retina, yet there isonly one single sensation experienced as long as the images are formed in the corresponding points of the two retinas. The two yellow spots represent in normal conditions respectively the corresponding points in the two eyes so that when the image of an object looked upon falls on the two yellow spots it is seen as an object. The portion of the left retina to the inside of the yellow spot corresponds with the portion of the right retina to the outside of the right yellow spot and vice versa. If one eyeball is displaced by means of pressure the images are not formed on corresponding points of the two retinas and double vision results. If the other eye is displaced correspondingly then the vision becomes single as the image falls upon the same point. There are thus corresponding points on the two retinas, the two yellow spots coinciding, the upper and lower parts in each retina corresponding and the interior of the left retina corresponding with the exterior part of the right retina. If an object is viewed from a number of points the object will be seen singly from all the objective points provided the angles from the points to the two eyes are equal. A line joining these points representing the objects will represent the horopter which is the circular line connecting different points in the visual field, forming images on the corresponding parts of the retina, or the sum of all the points seen single by the two retinas while the point of fixation remains the same. All the points not included in the horopter will represent points at which objects will be seen double. If the eyeballs are so fixed or acted on by the muscles as to see objects not in this horoptric line there is a double vision representing the strabismus or squinting condition of the eye, as distinguished from true binocular vision. The eye itself normally is a mechanism whose movements are so directed on the principle of convergence as to secure single vision. There is thus not only the power of converging the eyeball so as to focus the rays upon the yellow spot but also the power of accommodating the vision to the object and its distance. The rectus externus and the rectus internus have here a function to discharge of special importance in regulating the convergence. If in looking at a distant object the axes are parallel accommodation is suspended. If, however, the axes are turned internally there

is a contraction of the pupil due to the contraction of the ciliary muscles. The two eyes rise and fall together leaving the line of vision in a single plane. Corresponding to the retinal points in the blending of images are the brain centers at the terminal of the optic nerves. This implies that there is a consciousness of a single image upon the retinas; even when the two images on the retinas differ there is a psychic power of fusing the two images into one. When an object is photographed on the two retinas although the retina represents a plane there is a power to produce an image representing all sides of an object in space. Although the pictures on the retinas differ a fusion takes place by means of which a single object is seen.

(1) Wheatstone propounds a theory to explain the single object by claiming that when there are different pictures they are reduced to unity by the mind and that in this mental diffusion of different pictures we have the basis of distinctions between depth, solidity and relief. In this way the mental perception and judgment become the bases of space conception. The objection to this theory is that the mind does not fuse these retinal pictures but the mental operation has to do with ideas based upon comparison of objects of pictures or pictures themselves. (2) Brucke's theory. According to this theory both eyes are constantly in motion, the convergence taking place from side to side so that the object is viewed on all sides, thus giving rise to the sensation of depth, solidity and relief in space. This means that when nervous impressions arise in connection with the muscles of the eyeballs then there results a perception of the qualities of objects in space. It has been pointed out that when there is a certain flash of an object too rapid for the production of convergence there is still a sensation of depth, solidity and relief. According to Wheatstone this indicates that the sensation of relief is immediate, although this does not exclude the nervous impulses which take place reflexly, however sudden the object may pass and repass before the vision. This fusion of objects that are dissimilar seems to depend upon the physical and mental accommodation which by habit comes to be most perfect, even without distinct consciousness. The sense perceptions of vision if they exist for a definite length of time are referred to as external objects. This depends upon habit. In the case of persons who have been blind from birth to whom sight has been restored, there is not the same sense of externality in the objects of vision as they are supposed to be nearer the eye. Gradually by a process of training in conjunction with the tactile sensations the sense of vision becomes familiar with external objects and their relations. The image of external objects upon the retina is inverted and yet in sense perception these objects are vertical. Consciousness is concerned not with the image of the retina but with the rays of light that produce this retinal image, as these rays of light emanate from some luminous object. Even when different images are thrown upon the retina by the running of the eye over a large object we are unconscious of the varying segmentary pictures produced on the retina and become conscious only of a single object, the movements of coordination bringing all the parts of the object in succession upon the central point of rotation. Objects can be localized by their relations to other luminous objects in space placing the eye in a definite position so as to be able to discern those relations. In a dark space, for example, we cannot locate a luminous body unless there is another luminous object with which to compare it. Thus we localize by observing the relative position of objects. If a luminous

ray of light falls upon the retina it will be seen as a single line, even although it is placed upon a number of rods or cones, each rod or cone being excited by a single sensation. The same thing is true of a surface whose image is cast upon the retina, the different parts corresponding with the portion upon which the image falls. All the separate images are blended together in the formation of a complex image. The retina being an arched surface when a long straight line is seen at a distance it appears curved. In regard to the size of an object, especially in connection with a small object judgment is based upon the size of the retinal image in relation to the visual angle. If on the other hand the object is very large, size is determined in connection with the muscular sensations associated with the movements of the eye, as the eye passes over the different points of the object.

In regard to distance the eye judges (1) from the size as determined by the angle of visual observation formed by the marginal rays of light falling upon the retina; and (2) from the intervening objects between the object viewed at a distance and the eye. In the case of a water surface it is very difficult to estimate the width of water between the eye and a distant object because there are no intervening objects which can form a basis of comparison. That this is the case can be easily proved by looking at a distant shore with a number of ships intervening between the shore and the eye. In the case of the fixation of the eye we determine the movement of a body by the fact that successive parts of the retina are affected by the rays of light falling upon it reflected from the object. In the case of the eye moving after the object we have also muscular sensations associated with effort; these sensations are intensified if the head or neck is moved and also if the upper part of the body is moved in connection with the moving body. In the case of the pupil of a normal eye it is dark and the internal part of the eye is invisible unless it is illuminated. This darkness does not exist on account of the absorption of the rays of light that fall upon the fundus in connection with the choroid tunic of the eye. That this is so is proved by the fact that the pupil of an individual deficient in pigment seems to be dark if the eye is covered by a black surface with a small hole before the pupil. The eye receives its rays from all directions and if the eye is illuminated rays are sent out from the eye in all directions. If the eye of an observer assumes a position before the eye of the observed, the observed eye does not see light from the part of the visual field filled by the pupil of the observing eye and for this reason it does not reflect light into the observing eye. This defect is compensated for by the use of the ophthalmoscope. The original form of this instrument is a single plate or several plates of glass placed over each other from which a ray of light from a lamp is reflected into the eye that is observed as the observing eye looks through it. This gives only an imperfect ophthalmoscopic view, hence a concave mirror which has a small perforation in the center for the pupil of the observing eye to look through is commonly made use of. When the eye is examined directly the mirror is placed close to the examined eye with the result that an image is seen of the base of the eye. If the eyes of the one observing and the one examined are emmetropic the rays of light as they pass from a point in the retina of the examined eye become parallel in connection with the dioptric media and are focused on the retina of the examined eye. If the eye examined is myopic the light rays as they pass from a point of the retina pass out from the eye in a convergent form.

The eye of the person examining if emmetropic and unaccommodated requires a concave lens in order that the base of the eye may be seen distinctly. If the eye examined is hypermetropic the rays of light as they pass from the eye become divergent and are focused behind the retina of the examining eye and a convex lens requiresto be pu tbefore the examining eye in order that the fundus may be seen distinctly. In this way by the use of the ophthalmoscope errors in refraction may be discovered and measurement made of the error. It is essential that the eye of the observer be unaccommodated and that the eye be emmetropic or if not that the amount of the variation either in long or short sight be known. In this latter case the lens that is required to correct the defect of refraction in the observing eye requires to be known in order to calculate the error in the eye of the patient. In order to render the eye unaccommodated atropin is commonly made use of. In connection with the direct ophthalmoscopic examination of the eye only a small part of the retina is able to be seen at one time and this part is very much magnified. In order to enlarge the amount of the retina that is seen the indirect method is made use of. The eye that is examined is illumined just in the same way as in direct examination, but the mirror and the eye of the observer are placed at a considerable distance. The result is that the rays of light as they pass from a large part of the retina pass out as parallel waves, if the eye is unaccommodate and emmetropic, with the result that the rays are focussed by means of a convex lens close to the eye examined with the object of forming a real and inverted image of the retina. In connection with normal vision the retinal image represents the projection of external objects on the surface; yet we perceive not only the surface of the object but also its solidity. If an object is looked at directly the form of the image is the same in monocular and binocular vision. But if an object is viewed from one of its ends we get an impression of its solidity in connection with binocular vision. This arises from the fact that in order to the fixation of points at different distances from the eyes there must be a convergence of the visual lines and the extent of this convergence is judged by the muscle contractions that regulate convergence. In addition to this if the two eyes look at a plain surface of uniform color the resulting retinal image is the same in both. If on the other hand the two eyes look at a solid body the image that is formed on the right retina differs from that formed in the left on account of the fact that the left eye can see more of the left part and the right eye more of the right part of an object.

Vision involves judgment and judgment represents psychic processes. The retina may be represented ideally as well as from the standpoint of development as a projection forward of the cerebrum, representing a superficial organ for the purpose of receiving the light rays that fall upon it from all directions so that from a physiological standpoint the retina, the optic nerve and the center of vision are indissolubly associated together. The result of this is that sight cannot be said to be localized either in the retina or in the optic nerve or in the center of vision. The rays or waves of light fall upon the retina and orginate impulses which pass up along the optic nerve, with the result that certain parts of the brain are stimulated to action, certain sensations being aroused. These sensations of light are in some way translated into perception of external objects and also into judgments in regard to the relations of these objects to each other, to the body organism and of their distance from each other and from the bodyorganism. In connection withthe stimulus of ligthwhen applied to the

retina there is the liberation of energy, associated with which we find a latent period, a period during which the effect produced by the stimulation attains a maximum, a period during which the after effect of the stimulation continues representing a period of fatigue and lastly a period during which the effect of the stimulation slowly disappears. There is undoubtedly a latent period of sensation in connection with the retina. The sensation of light attains its maximum quickly especially if the light intensity is increased; there are also variations in the attainment of this maximum in connection with color, red light giving a maximum sensation before green light. Hence if the picture of a white object passes over the retina it will be seen to be colored at its margin on account of the fact that the various elements of the white light do not give their maximum results at the same time. In connection with what are called recurrent images, if a black disc containing a white segment is made to rotate once or twice in a second and if the disc is lighted up by a bright light while the eye is fixed upon the rotary axis the white section as it moves has cast upon it a dark shadow, this shadow having after it a second shadow and a third, these shadows becoming more dim until they disappear. This indicates that when light is quickly allowed to fall upon the retina the sensation does not all at once attain its maximum, but attains this maximum in connection with oscillatory activity on the part of the retina. If the eye is fixed upon a white surface of uniform whiteness we are not conscious of the lessening of the sensation intensity, but as we continue to look at the white surface the retina is fatigued and the light seems to be less bright. The fatigue of the retina depends upon the color of the light. If white light falls on the retina the eye passes through certain changes in connection with tre disc so that the sensation of white becomes less distinct on account of the fatigue of the retina. After the stimulation has ceased the sensation continues to be experienced in connection with the eye. The period during which the sensation persists varies, depending upon the length of stimulation and also upon the color of the light concerned in the stimulation, the red light giving the most persistent effect. If an object looked at by the eyes is very bright the retinal impression may persist to such an extent that the appearance and even the color of the object may be visible for a considerable time after the stimulus has ceased. This is called the positive after image and may best be illustrated by closing the eyes after gazing at the sun with the result that there is a perception of a bright light spot. Sometimes there is associated with this a negative after image which depends upon the fatigued condition of the retina. The difference between the positive after image and the negative after image is that the latter always appears in the complementary color of that of the object producing it. If the eye passes over a field of vision from one part to another the sensation that is caused by one part of the field is modified by the fatigue associated with the retina in connection with the part of the field on which the eye rested just before. The result of this is that the sensation will be found to be the result of the stimulation arising from the object looked at together with the negative after image produced by the part looked upon just before.

In connection with this we have contrasts in connection with vision. Hence one part of the field of vision seems to be dark when close to a lighter part and vice versa; and if one color is seen near to another color the color approaches to the complementary color. If the negative after images are not involved then the contrast is spoken of as simultaneous and

is explained by the fact that when a given part of the retina is stimulated there is produced in the contiguous parts a result that is really the opposite of that produced by direct stimulation. The light rays as they pass from the different parts in the visual field are refracted to and result in the stimulation of a distinct part of the retinal surface, giving us a local sign which enables us to localize the point from which the light emanates. From this standpoint the form and the size of a retinal image enable us to judge the size of the object. This gives us space perception and it is materially assisted by the muscular sensation in connection with the movements of the eyeball. The retinal perception of space can only extend to two dimensions,the third dimension, that is, in regard to the distance of an object from the eye is not perceived by the retinal image. When an after image of a bright body isimpressed upon the retina and the eye then looks at a white piece of paper the bright object will be pictured on the white surface. If after this the eye is raised and fixed upon a bright surface the object will seem to be larger and to stand at a distance that corresponds with the size of the surface. In this way the retinal image may produce the impression of different distances according to the size of the surfacelooked at. Hencetheperceptionof thethirddimension in space namely, distance, is not a direct visual perception but rather a visual judgment. If objects are of such a form that their pictures can be successively thrown upon the retina the eye can judge of the relative size of the object, the retinal surface assuming the part of a measure to which the images of the objects are applied. If the objects are of such a form that they cannot be thrown successively on the same retinal point there is an error in judgment. One of the most important modifying influences in connection with space perception is the intensity of the light. Hence where objects are very bright they seem to be larger than those that are less bright. This is spoken of as irradiation and depends largely upon the imperfect condition of the eye as an optical instrument, on account of which rays of light produce circles of diffusion in connection with the retina and very luminous objects produce images that are not perfectly outlined. The irradiation effect becomes more distinct if the dark part of the visual field in connection with which irradiation takes place is extensive. If the visual field is subdivided into small parts either by intermediate lines or objects it seems to be larger than if the same space is undivided. The reason of this seems to be that as the eye passes over a field divided up by lines or objects the eye recognizes the subdivision and its impression of size is based upon these subdivisions. The eye estimates the size of lines as well as areas and angles by comparison with other lines areas and angles. The ordinary retinal image does not give us any direct information of the distance of an object from the eye. Distance is closly related to size in connection with visual judgment. Hence if we know the size of an object its distance is determined by the size of the image cast upon the retina and on the other hand our judgment of the size of an object depends to a large extent on our judgment of distance. In children there is found an error in connection with the appreciation of size and distance, indicating the absence of that training and experience necessary for such judgment. When the retinal image assumes a familiar form we interpret its size and distance by past experience.

In connection with vision it is important to remember that scientifically the eyes are often used in a particular way as distinguished from their habitual use with the result that vision is limited on account of ner-

vous and muscular exhaustion. There is a tendency thus to limit the field of vision. In this way the eye becomes a specialist in certain fields of vision. The eyes like the other organs of the body seem to be most perfect when the mechanism is freest without restraint. Hence in normal vision we do not take account of the fact that the eye is optically defective and the forgetfulness of this fact is an aid to vision. To emphasize the defects of vision means the making of the eye sensitive under certain conditions unfavorable to ordinary vision.

SECTION III. The Sense of Hearing.

The ear is an apparatus constructed for the purpose of allowing sound to stimulate the fibres of the auditory nerve. In very simple forms the ear is found in the invertebrates as a simple hair-like appendage in connection with a depression. As we pass to the higher animals the ear becomes more complex. It consists of the external ear, formed by the concha and the external auditory canal; the mid-ear, a cavity that is filled with air connected by the Eustachian tube with the throat and divided from the external ear by the tympanic membrane, this tympanic membrane being associated with the oval fenestra in connection with a series of bones or ossicles called the malleus, incus and stapes; and the internal ear, a complex structure that is filled with fluid including the vestibule, the semi-circular canals and the cochlea. The essential part of the apparatus is the internal ear, consisting of three parts, the three semi-circular canals and the cochlea, these two being connected together by the vestibule. The vestibular wall is penetrated by the oval fenestra, covered over by a membrane in connection with which we find the stapes. The vestibule has seven media of communication the oval fenestra, the vestibula scala of the cochlea and the openings of the semi-circular canal. In connection with the vestibule we find small crystal masses to which the name of otolith has been given representing the granules of calcium carbonate in the labyrinth of the ear. In connection with the walls we find projecting hair-like bodies originating from cells in connection with the terminals of the vestibular branch of the auditory nerve. These represent the specially modified cells at the termination of the fibres of the auditory nerve. In connection with the labyrinth of bone we find a membranous labyrinth which consists of the utricle which forms the communicating medium with the semi-circular canals and the saccule that communicates with the cochlea duct. The semi-circular canals are the horizontal, the posterior vertical and the anterior vertical which when extended forms the ampulla. There is a common tube by which the anterior and the posterior vertical canals communicate with the vestibule. The cochlea represents a tube that is narrowed towards one end turned around the columellar axis. It consists of two cavities, the division between the two cavities being found in connection with the osseous and membranous partitions. From the margin of the osseous separation there are two slanting membranes which divide off the triangular space, this space containing the most important elements of the auditory organ. From the free margin of the osseous partition there passes the basilar membrane in a transverse direction. There is a second membrane passing from the osseous partition to the osseous tubular wall. In this way the cochlea tube is separated into three parts, the vestibular scala that communicates with the vestibule, the tympanic scala that communicates with the tym-

panum and an intermediate scala lying between these two. Between the basilar membrane and Reissners membrane there is a space which is called the cochlear canal and in connection with the basilar membrane we find the corti rods representing a number of arches that bear up cells with hair like projections which represent the vibratory parts of the auditory organ. These corti rods bear up a number of cells called hair cells. In the human subject there are six rows of these cells one over the internal and the remainder over the external cells. In the internal ear we find two membranous sacs in communication with one another by means of a duct, the smaller sac or utricle is in connection with the semi-circular canals while the larger sac or sacculus is in connection with the cochlea duct. These parts of the membranous labyrinth are encased in cavities in connection with the petrous part of the temporal bone. Between the membranous and the osseous partition is found the perilymph and in the internal part of the membranous labyrinth is the endo-lymph. In connection with the walls of the utricle, the saccule and the semi-circular canals we find three layers, one of connective tissue, one of hyaloid membrane and one of the tesselated epithelium. As the fibres of the auditory nerve come into connection with the labyrinth modification takes place in connection with the cristae acusticae. At these points the connective tissue and hyaloid layers become more dense and the tesselated epithelium becomes cylindrical becoming neuro-epithelial. In connection with this neuro-epithelium we find elongated cells and also hair cells on the upper part of the epithelial layer, the upper surface having a number of delicate fibres which form the auditory hairs. It is in connection with these hair cells that we find the nerve fibres. As the fibres of the vestibular branch of the auditory nerve pass into the epithelium they lose their medullation, the axis cylinder passing along the margin of the hair cells and forming a terminal organ in connection with those hair cells. The cochlear branch of the auditory nerve passes into the cochlear axis, its branches passing to the osseous partition at its root where the fibres pass into a mass of cells turning around the cochlear axis. Out of this ganglionic mass the fibres pass in connection with the plexus towards the tympanic limb where they cease to be medullated and terminate in the epithelium. In connection with the middle ear the tympanic mucous membrane consists of connective tissue. It is covered by a single layer of ciliated epithelium except on the roof the ossicles and the tympanic membrane. The blood vessels that are found in connection with the tympanic cavity form a plexus whose meshes are narrow, the minute blood vessels being twisted around the glands. In connection with the external ear the drum consists of a layer of connective tissue which are found to radiate in bundles on the upper surface becoming continuous with the periosteum of the tympantic prouves. Around the surface close to the tympanum are found circular fibres while the drum is covered on the internal surface by the tympanic mucous membrane and on the external surface by a part of the lining membrane that is found in connection with the auditory meatus. In the external auditory passage we find the ceruminous glands. These glands are very similar to sweat glands, the ducts being found to possess epithelial cells while the main part of the gland has the cuticle cells that rest upon a membrane external to which we find the unstriped muscle. They differ from the sweat glands in the fact that they have a wider bore and that their cells contain pigmentary granules and fat globules. The wax that is secreted in connection with these glands is found to consist of fatty

particles, pigment and fatty cells. The external and middle ears discharge the function of collecting and modifying the sound waves. Sound is produced by the vibrations of an elastic body or bodies and transmitted through an elastic media, usually the air. These vibrations consist of oscillations. If these vibrations are communicated to the ear with proper rapidity and with sufficient intensity the result produced is a sound sensation.

Sound travels to the ear usually in connection with the air. Sound travels much faster in water than in the air and still more rapidly along any solid substance capable of vibration. In connection with an elastic body molecular movements forms the basis of vibrations. As the vibration passes along a medium the different parts of the medium pass through the same modifications, the waves passing along all the different parts. The distance between two points in the vibrating body is called the wave length and it is found at the same period in the same vibrating phase; it is also constant for the same time in a definite medium if the vibrations are equal in number. From a physical standpoint there are two classes of sounds, noises and musical sounds. If the vibrations of an elastic body are periodic, that is, if every vibration is separated from the preceding and the succeeding vibration by the same interval of time the resulting sound is a musical tone. Non-periodic vibrations produce non-musical notes or noises. A noise may also be produced by the clashing together of a number of musical tones. The pitch of a sound depends upon the wave length, the shorter the wave, that is the greater the number produced in a given moment of time the higher the pitch and vice versa. The intensity of the sound depends upon the amplitude or height of the wave. The greater the amplitude the lower the sound is. The timbre, quality or klang of a sound is the peculiar character of the sound according to which we are able to recognize it as produced in a particular manner, for example, by the human voice, the piano, the violin, etc. It depends upon the complexity of the waves and upon the union with the fundamental or keynote of the upper notes. Hearing is a sensation produced by the stimulation of the auditory nerve under the influence of the vibrations of sounding bodies. In the external ear we find the auricle, and the external auditory meatus or canal at the end of which we find the drum head. The auricle of the human ear is irregularly shaped. If these irregular surfaces are filled up with wax or other soft substances sounds are not distinctly heard on account of the weakening of the sound. When the waves fall upon the auricle some of them are reflected outwards and others reflected inward towards the auditory canal. Along the canal the vibrations are transmitted by the walls and also by the passage of air to the tympanic membrane. Even if the auricle is absent there is not necessarily any loss of hearing, the waves being passed along the canal to the tympanic membrane. The middle ear represents a small cavity whose walls are solid except the tympanic membrane and the membrane that is associated with the round and the oval fenestrae. The middle ear communicates with the pharynx through the eustachian tubes constituting an air passage between the pharynx and the tympanum in connection with the regulation of pressure upon the tympanic membrane. This passage is closed during the resting condition and open or partially opened during deglutition. The air pressure in the tympanum is preserved in a condition of equilibrium with the external ear which acts on the external part of the tympanic membrane

so that the tympanic membrane does not depend upon changes in the pressure of the atmosphere. If a forcible expiration admits air that is driven forcibly into the tympanum, there is produced a characteristic cracking sound in the ear. Similarly a forced inspiration, associated with deglutition, draws air away from the tympanum, producing a cracking sound, causing temporary occlusion. In both cases, on account of the tension of the membrane, there is a temporary deafness. If the occlusion becomes permanent, permanent deafness results. In these cases, the tympanic tension is increased, but it is lessened in connection with the absorption of oxygen from the blood. It is necessary that the tube be closed, except during the process of swallowing, in order that the sound waves may be transmitted from the tympanic membrane to the internal ear, because if closure did not take place there would be found a change in pressure on the internal surface of the tympanic membrane at each respiration, resulting in the weakening of the sound. The tympanic membrane is made to vibrate when a sound of an audible nature and of a definite pitch is produced. The membrane gives response in connection with the vibrations, their number indicating pitch, their intensity the loudness, and the character of the vibrations the timbre. The tympanic membrane is fixed to the manubrium, the result being that resistance is offered to the vibrations of the membrane, lessening the intensity of the vibration and causing the membrane to cease vibrating when the external vibration ceases. The membrane tension varies according to the varying pressure upon the two membrane surfaces and by the contraction of the tensor tympani muscle. When the muscle relaxes the membrane assumes its normal position. This constitutes the power of varying the membrane tension for the purpose of receiving sounds varying in pitch, as the difference in tension makes it more easy to respond readily, and if relaxed low sound will call forth a response more readily. The special form of the membrane in the arrangement of the radiating fibres makes provision for the convexity of the membrane towards the tympanum, while the bands of fibres are convex towards the external auditory canal. This increases the force of the vibrations. The vibrations of the membrane are communicated to the internal ear by means of the air in connection with the tympanum and by the arrangement of the bones, the malleus, incus and stapes forming a lever, the incus being the fulcrum, the power being in the malleus and the resistance in the stapes. This tends to lessen the extent of the vibrations while increasing the force. In the transmission of vibrations of the tympanic membrane from the membrane to the internal fluid of the labyrinth the chain of bone vibrates as a whole. The sound wave exerts pressure upon the tympanum, the drum head moving inward and the malleus being borne inward along with it, at least the handle of the malleus, while the head moves outward along with the incus, the long process of which passes inward. By this movement the stapes is pushed into the open cavity. The connection of the malleus and incus is such that when the head of the malleus moves the incus is taken along with it. By the movement outward of the drum head on account of the diminution of the pressure of the sonorous wave on its external surface we find the reverse of these modifications taking place, while the head of the malleus and the incus separate from each other, the incus bearing along with it the stapes, so that there is prevented the sudden movement outward

of the drum head. The drum head is peculiar in form. The funnel shape of it and its structure of small membranes permits of its action in parts, the tension varying, being greatest at the middle of the membrane and least at the sides. In this way the drum head is able to transmit several tones, having no intrinsic tone of its own. The drum head is so solid and so completely weighted in connection with the chain of bones, that vibration ceases as soon as the producing cause of the vibration ceases. Hence, as soon as the external vibration ceases, the drum head ceases to respond on account of its rigidity and its close and solid connection with the bones. The bones of the head act as conductors of sound to the ear. If a watch is placed between the teeth its sounds can be heard distinctly even if the ears are stopped, although the sound is not heard for such a length of time. The sound vibrations may reach the fluids in the internal ear either by the bony walls of the labarynth or by the air in the tympanic cavity acting in connection with the round fenestra, or by the base of the stapes placed in the oval cavity. In normal hearing the vibrations are transmitted by the chain of bones. If the base of the stapes is pressed into the oval fenestra, the labyrinth pressure is increased, with the result that the impulse is made to pass along the vestibular passages to the tympanic passage, and on account of the fact that the only part of the wall of the labyrinth that is movable is the membrane over the round fenestra, this membrane is pressed outward. If the base of the stapes is pressed outward, the opposite of this takes place. In this way the labyrinth fluid may receive a number of impulses corresponding with the motions that are associated with the base of the stapes, these impulses being imparted to the terminal apparatus in connection with audition. The membrane of the labyrinth is small, being only about one-tenth of an inch in diameter at its widest part so that the vibrations must be transmitted by impulses varying in character, the complex character of which is unknown.

Sonorous vibrations must, in order to produce a sensation of sound, reach and stimulate the terminations of the auditory nerve on the internal ear. They may reach the internal ear through the bones of the skull as when a tuning fork is placed in contact with the head; but as a rule the sound waves travel through the air and reach the internal ear after passing through the middle and external ears. The sonorous vibrations are collected, therefore, in the pinna, passed down the external auditory meatus and strike against the tympanic membrane in the oval window. This is thrown into vibration and the vibrations are communicated to the air in the middle ear by which they are conveyed to the secondary tympanic membrane. This is thrown into vibrations. Of much more importance is the fact that the tympanic membrane by its oscillations causes the bridge of ossicles to be thrown into vibrations. The oscillations of the tympanic membrane are communicated to the malleus from which they pass to the incus and thence to the stapes. The bones of the stapes are thus alternately driven inward and outward, striking against and setting up waves in the perilymph of the internal ear. Through this the waves reach the membranous labyrinth, the auricle and the semicircular canals, striking the endolymph and stimulating the hairs of the columnar cells in connection with the fibres of the auditory nerve. The vibrations of the perilymph also pass forward along the scala vestibuli

through the helicotrema or opening between the two scalae of the cochlea, down the scala tympani as far as the secondary tympanic membrane in the fenestra retunda. As the vibrations pass along the two scalae they are communicated to the endolymph in the membranous cochlea and so to the hairy cells of the organs of Corti. Through these again the fibres of the auditory nerve are stimulated. The internal ear has little or no physiological function beyond the mere transmission of the sound waves. The bridge of ossicles has the function of conducting the vibrations of the tympanic membrane to the external ear. We have seen that in doing so it acts as a lever diminishing the extent of the vibration in the proportion of three to two, but increasing their force in the proportion of two to three. Further the attachment of the handle of the malleus to the tympanic membrane prevents the latter from continuing to vibrate after the waves of sound have ceased to fall upon it. The tensor tympanic muscles by its contraction pulls inward the handle of the malleus and so makes more tense the tympanic membrane. Hence by varying the conditions of the tensor tympani muscle the membrane is accommodated to sounds of varying pitch. The stapedius muscle tends to draw the head of the stapes backward by its contraction and thus to separate partially the stapes from contact with the long process of the incus. At the same time it will hold fast or fix the stapes or at least diminish the range of movement. Thus by its action the stapedius muscle will save the delicate structure in the internal ear from vibrations of so excessive a degree that they might be injured by them. The Eustachian tube admits the air into the middle ear and through its agency the pressure on the two sides of the tympanic membrane is kept uniform. If this was not the case difficulty of hearing would be produced.

Nothing certain is known of the special functions of the different parts of the internal ear. It is generally stated that the semicircular canals have to do with the judgment of the direction from which sounds proceed. Formerly it was thought that the rods of Corti were associated closely with the appreciation of the pitch of sound, each note having a particular rod or rods which it threw into vibration. This is not the case because the rods are non-vibratic structures. It has been suggested that the basilar membrane is as it were strung up to different degrees of tension at different levels and that any particular sound causes the vibration of that particular part of the basilar membrane which is tuned to that sound. In other words, different parts of the basilar membrane respond to sounds of different pitch, while perhaps the rods of Corti act as a deafening apparatus to the basilar membrane. In order to excite the auditory nerve so as to produce a sensation, there are three essential conditions, (1) there must be a definite amplitude in the vibrations; (2) there must be a definite duration in connection with the impulse. If the duration is shorter than one-thirtieth part of a second or if it is greater than one-forty-thousandth part of a second the impulse will fall within the necessary limits; (3) There must be a definite number of impulses within a specific limit of time in order to have a tone sensation. The limit between the maximum and the minimum has been placed at thirty thousand and thirty vibrations per second. Above or below these limits sounds are not detected by the ears. In the case of the highest audible sound Koenig has shown that the wave length is about ten millimeters. The strongest tones are found in connection with small tuning forks in connection

with which vibrations of 40,000 in connection with tone have been heard. Ordinary individuals can detect a tone varying from 5,000 to 30,000 vibrations. In these cases of a simple tone we find that it depends upon variation in pressure of the atmosphere close to the ear. The air vibrations may be either simple harmonic or they may be in elliptical orbits produced by the combination of two simple harmonic vibrations. The variations in air pressure close to the ear depend upon the law of harmonic motion, which is that the velocity of the air and of the vibrator in the region is infinitesimally small as compared with the velocity of the sound. If this law is followed we have simple harmony in tone, if it is not observed and the air passes with great velocity past the margin of the vibrating body then the tones are harsh and deep. A sound may be characterized by its loudness or it may give a characteristic pitch. In addition to this the quality or the timbre of a sound may be peculiar. The intensity of sound depends upon the extent of the amplitude in connection with the vibrations. The result is that the stimulation of the terminal organ will depend upon the amplitude. A weak sound will not cause so great a vibration as a strong sound. Sound pitch depends upon the number of vibrations that are found within a certain period of time. Relative pitch is determined by the relation of one sound to another, in some cases this being determined by the memory of former sounds. The quality or timbre of sound enables us to determine the origin of the sound or its relation to a particular instrument that produces the sound. This depends upon the form that is assumes by the sonorous wave or the wave of vibration.

In order to appreciate the quality of sound there must be a mechanism associated with the ear capable of analyzing complex waves of sound into the more simple vibrations. A sound is considered to possess a certain pitch, this being determined by the vibrations of a particular key tone or fundamental tone. The quality of the sound is determined by the relation of this fundamental tone to the number and the intensity of the other tones, which are called in relation to fundamental tone overtones. The connection of these overtones to the primary tone is simple, the number of vibrations being multiple of the primary tone. A harmony represents a sound in connection with which the changes that are found in the air pressure are periodical. Wherever there is periodical vibration in quantity, we find the sum of quantities that vary separately on the basis of the simple harmonic law, the periods representing a full period, a half period, a third period, a fourth period, etc. According to this, the changes that are found in the air pressure of a harmony represents the sum of the variations in connection with the simple tones. Thus a harmony consists of simple tones. The quality of a harmony is determined by the amplitude of the tones which constitute it, and also by the period of the tones and the relations sustained by the different variations. Tone relations are studied by means or tuning forks. In the combination of sounds in connection with a number of tuning forks, whose vibrational numbers are represented by multiples of the first tuning fork, we get various qualities of tone and are able to determine the increase of intensity in one tone as compared with another. Compound tones may be analyzed by the use of resonators in connection with the ear. It is not definitely known what takes place in connection with the fluid as it vibrates in the labyrinth, nor is it known how these vibrations affect the terminal organs in connection with the auditory nerve.

Its action is mechanical, the impulse being imparted to minute processes, which, by their motion, produce stimulation of the nerve fibres. There are said to be about three thousand minute arches in in connection with the Corti rods. Each of these arches is supported by the basilar membrane forming a base for cells arranged in layers with cilia-like processes. The fibres of the Cochlear branch of the auditory nerve end in these minute cells associated with the basilar membrane. Helmnoltz supposed that the fibre roots of Corti were elastic, all of these fibres being attuned to represent all the possible audible tones found in connection with the ear. Thus 3,000 fibres give us 7 octaves of tones with about 430 fibres to an octave. According to this theory when a vibration reaches the ear it arouses the fibres which are tuned to its pitch. In the case of different fibres attuned to different tones we have an apparatus which in connection with stimulation of the different nerve fibres produces pitch sensations. If there is a compound sound representing different vibrations then the ear may analyze this compound sound into the simple tones corresponding with the fibres tuning. In this way we are said to have the sensation of pitch. This can be done only if different fibres give a response to the different sound vibrations, the one in connection with the primary tone being the strongest with the result that the sensation of a particular pitch is given while the others being feebler give different sensations which are united together in connection with the production of a complex sensation. An objection has been taken to this theory for the reason that 33 of the Corti fibres in connection with a semitone do not give us sufficient variations in connection with pitch ; this objection is based upon the fact that musicians can detect differences of one sixty-fourth of a semitone, whereas, according to this theory, there can be but 36 variations to the semitone. Helmholtz in answer to this, stated that if a sound is produced which does not correspond with the pitch of any fibre it will arouse the two fibres between which it lies, the vibration coming nearest to the sound pitch having the greater intensity and consequently prevailing. In this way the pitch of the sound can be easily appreciated.

Hensen has confirmed this theory by discovering delicate hair processes in connection with the antennae of the Mysis in connection with the microscope, these processes being subjected to vibrations by the use of a key. He found that when certain tones were produced certain hairs vibrated, indicating the basal tract of the Helmholtz theory to be true. Recent histological investigations have raised an objection to this theory in the fact that the Corti rods are not flexible, and hence not physiologically capable of vibrating but forming a base for the support of the minute hair cells. Helmholtz suggested that the basilar membrane segments are stretched radially more than longitudinally, and in connection with the radial stretching different tension degrees are developed, rendering it possible to appreciate different degrees of sound. When these vibrations are brought in connection with the fibres, in whatever way this connection is established, they must be communicated to the brain. As each auditory fibre comes from the cochlea it will be stimulated by its own hair processes or cells, each fibre carrying impulses corresponding with the intensity of the vibration. In this way impulses varying in number and character will be carried to the brain cells producing sensations of

sound differing in pitch. Some question the capacity of the ear to appreciate the vibratory phases in the case of two or more tones being sounded together. Helmholtz thinks that the ear only takes account of vibrations without recognizing any variations in the form of the waves. He claims that by sounding different tuning forks at different periods of time no difference can be noticed in the tone quality. Lord Kelvin maintains on the other hand that the ear does appreciate difference in phase. By using the sharp and flat topped and the flat and sharp hollowed curves, he proved that the ear can distinguish the quality of tones. According to this the ear distinguishes between the pull and the pressure in connection with the tympanum, and in this way is able to distinguish harmonic relations. Normally the auditory sensations are supposed to refer to the external world, the brain, when a sound is heard, associating the sound with an external producing cause. This seems to indicate the passage of the sound through the tympanic membrane. If the head is placed in water, then the sounds that are caused to pass through the cranial walls must travel through these walls, and they seem to be associated with the whole body. Hence it is suggested that the reference of sound sensations to an external origin is due to a custom. There is not the same sensibility to all sounds, the ear being more sensitive to acute sounds, although the sensitiveness varies in different individuals. This power of appreciating differences in pitch depends very largely upon habit and especially upon training. Auditory sensations persist after the exciting cause has been removed, so that if we find a number of distinct vibrations, these may give rise to separate sensations or if they follow each other very rapidly may give rise to a fused sensation. The fact that we hear with two ears does not appreciably affect the auditory sensation. It is probable that the double organ assists in hearing sounds, especially in localizing the origin of a sound.

It has been stated that normally there is a difference in the capacity of appreciating sounds in the two ears. This has not been proved, however, as two tones of similar intensity at the same distance from the two ears are appreciated as a single auditory sensation. It is not easy to find out whether stimulations of corresponding elements in connection with the two ears can be separately distinguished. There is probably the power of distinction of the variation is sufficient to form the basis of such a distinction. It is not only possible to have single sensations, but it is also possible to have simultaneous sensations, as in the case of musical harmony. In the combination of sounds, as in music, there is in the ear the capacity of separating the auditory sensations, at least where the single sensations are distinct enough to be perceived. Concord depends on the agreeable sensation resulting from the reception of two or more miscellaneous tones in the ear, discord representing the disagreeable sensations resulting from the same cause. These depend upon the proportion of the vibrations in the case of two tones. The most generally accepted theory in regard to auditory sensation takes for granted that the vibrations in connection with the perilymph and endolymph or either of these two are communicated to the basilar membrane. This membranous structure is analogous to a wire sheet, after the fashion of the keyboard to a piano. The different radial fibres in connection with this basilar membrane are set into vibrations sympathetically by different vibratory rates in connection with the fluid which surrounds them. When these

vibrations are originated they are passed to the Corti organs, with the result that the stimulation excites the nerves that are in connection with the Corti cells. As the osseous canal of the cochlea is lessened in diameter the membranous canal of the cochlea increases in diameter, with the result that the radial fibres in connection with the basilar membrane are longest close to the cochlea apex. This produces the tendency to respond to the vibration when stimulation takes place in connection with the Corti organs. Tones that are produced in connection with these vibrations are said to be harmonious or concordant if no beats are produced when they are sounded together. If the beats are produced they are said to be non-harmonious or discordant, with the result that a painful sensation of dissonance is produced, and this painful sensation is increased in intensity to the point at which about 34 beats per second take place. Perfect harmony is associated with the blending of notes whose vibration "are to each other as small whole numbers." If the ratios of the vibrations in connection with the notes are represented only by large whole numbers then there is a discord on account of the fact that the upper partials are in conflict and produce beats which result in discordance. In the sounding of two notes together a new note is produced which is feebler and its vibration rate is represented by the difference in the vibration rates of the two original notes. This is called the differential tone. These differential tones may be found associated with the upper partials as well as in connection with the fundamental tones. Different other forms of combined tones may be found in connection with vibratory interaction in the sounding together of different tones. In order to gain the auditory result of this combination of notes we must take account of the intricate relations of the different notes and the impression that is made by them upon the tympanic membrane. The ear is very subject to fatigue in regard to a note that has been sounded. If a single note is struck in connection with the major chord of the piano and then the full chord be sounded, there will be a difference in the quality of the sound of the full chord on account of the sounding of the previous note. From this standpoint it is claimed that there is a successive contrast taking place in connection with auditory sensation on the basis of which sound perceptions are compared with preceding sound perceptions. There are certain modifications of the action of the auditory mechanism which make it impossible to transmit a perfect sound in connection with the external and middle ear. Helmholtz says that the cause of the origin of different combinational tones is due to a periodic clicking in connection with the jointure of the malleus and incus. On account of ear resonance tones of a high pitch become strengthened so that the auditory sensation has an excessive loudness. This resonance is found in all probability in connection with the external auditory meatus because this resonance is completely destroyed when a small resonator is applied to the ear. It is in connection with the ear that we gain our perceptions of small periods of time. In case of visual sensations, if the light flashes occur at the rate of 25 to 30 per second, they are fused into a single luminous impression; but in the case of the ear it is possible distinctly to separate at least 132 auditory impulses separately in a second. Hence in addition we find a much more delicate perception of slight variations. In connection with these separate impulses that are found in connection with the vibrations, their special char-

acteristic is periodicity. Musical tones are produced by regular periodic alternations of rarefaction and condensation in connection with the air. This distinguishes musical tones from noises, the noises being produced by an irregular succession of vibrations in connection with the air waves, there being a lack of constancy in connection with the rarefaction and condensation in the air. In connection with the functions discharged by the different parts of the internal ear in relation to perception the basilar membrane of the cochlea and the nerve elements associated with it represents the organ that receives and transmits the musical sounds. In this membrane we find a number of fibres capable of vibrating at every tone that is audible. The minute sensory hair-like cells that are found in connection with the maculae of the saccule and the utricle have been supposed by some to vibrate in connection with the vibratory action of the perilymph without any account being taken of the periodicity of these vibrations; and from this standpoint these have been regarded as the terminal auditory organs in connection with the perception of noises. These organs, however, as we will find later, are concerned in the function of equilibrium. The direction of sounds and the distance which sounds travel before reaching the ear cannot be directly perceived but can be perceived only by discrimination in connection with the intensity and the quality of the sensation of sound, when this discrimination is compared with past experience. In this discrimination there is usually a turning of the head in the direction in which the loudest sound is heard. Mistakes in judgment may take place on account of the fact that the sound which is reflected from a particular object appears to be louder than a direct sound coming straight from the object. In the case of the deafness of one ear sounds seem to be localized as originating on the side of the intact ear. The intensity and also the quality of the sound vary according to the distance of the origin of the sound. In this way tones that are lowered become inaudible sooner, thus bringing into prominence the overt ones. Ventriloquism is based upon the fact that it is possible to alter the quality of the sounds that are produced so as to stimulate the quality they would naturally possess if originating under different conditions.

THE SEMICIRCULAR CANAL.

These semicircular canals form a part of the labyrinth of the internal ear and yet their function does not seem to be very clearly associated with the sense of hearing. According to the old theory they were associated with the perception of sound direction, because the three canals were supposed to represent the three space dimensions. The three canals represent three planes that are at right angles, or nearly so, to each other, being called the horizontal, superior and posterior. The horizontal represents nearly the horizontal position in reference to the head, being always at right angles to the median plane. The superior and posterior planes form almost equal angles with the median plane. We cannot now observe the direction of sound in connection with these semicircular canals because such a perception can only result from two or more successive observations. When a louder sound is heard in one ear than in the other the head is turned toward the louder sound for the purpose of judging the sound direction, while if the sound is produced at equal distances from both ears we are unable to distinguish the position from which

the sound emanates unless in connection with visual sensations. It was discovered by Flourens that if one of the membranous canals is divided there is produced a rotary motion on the part of the animal around an axis at right angles to the divided plane, the movement taking place in the direction of the divided canal. This led to the theory that the semi-circular canals were associated in some way with the co-ordination of movement. Goltz discovered that when the head occupied different positions there would be always a pressure of endolymph upon the canal point representing the lowest part. By the excitation of the nerve corresponding with the different parts pressure would be localized and would produce the special sensations which would correspond with the changing attitudes of the head. If this arrangement is interfered with the sense of equilibrium would be lost or impaired. By the investigation of Cyon we have the theory that the semicircular canals give rise to a number of sensations of which we are not conscious, or at least only in subconsciousness, in reference to the attitude of the head; the loss or the impairment of the sense of equilibrium resulting from the interference with these sensations of equilibrium. Another theory formulated by Crum-Brown supposes that the three canals are filled with fluid and that when the head moves in a certain direction the fluid flows in the opposite direction the flow depending upon the plane around which the movement of the head takes place and also upon the rapidity of the head rotation. The fluid in its motion affects the auditory hairs in connection with the ampullar crista acustica at the dilated extremity of the membranous tube, causing a rotatory sensation of the head in the plane of the canal in which the fluid flows but in the opposite direction. By the continuation of the head rotation the fluid current flow will be stopped even if the head rotation ceases, the fluid flow will continue in the same direction as the head is rotated, producing a sensation of rotation in the opposite direction. There are two possible ways in which motion may take place in connection with the endolymph and the wall, a movement between the walls of the cavity and the fluid taking place, either by the motion of the head, in which case the fluid is left behind by the walls; or by the stopping of the head motion in which there is a continuance of the fluid flow. There is in both cases a rotary sensation. In the first case there is a real rotatory sensation while in the other case it is only apparent, although in both cases there is an increase in the rotation. According to this theory there are variations in pressure not only in connection with the endolymph but also in the walls of the membranous canals and in the perilymph; the double labyrinth is regarded as a single organ so that the six canals represent double parallel planes all of which are necessary in order to the rotatory sensations. According to this the six canals are divided into three pairs each pair being parallel, the two horizontal canals and the superior canal of the one side being parallel with the posterior canal of the other side. In connection with each of those pairs, the position of the two canals is such that in the rotation around an axis perpendicular to their plane there is the movement of one of the canals along with its ampulla before the canal, with the result that the fluid flow is from the ampulla to the canal, whereas in the other case the canal precedes and the flow of the fluid is from the canal to the ampulla. The stimulation of the hair cells takes place only while the fluid flows from the ampulla to the canal, so that

we have in the six canals a mechanism which can physically give us a perfect perception of the axis around which the head rotation takes place, while at the same time originating the rotatory sensation. In this way we have both the sensation and perception of equilibrium in connection with these semicircular canals. It is claimed by Cyon that by dividing the auditory nerve in the case of the rabbit, and causing the rotation of the animal, vertigo symptoms are induced. If this is true, then there seems to be no real foundation for the last theory, and this is the claim that is made by Cyon. According to him the semicircular canals represent the peripheral organs in connection with the spacial sensations. He claims that the sensations produced by the stimulation of the nerve terminals in connection with the ampulla originate the sensations that give us our perception of the three space dimensions.

In each of the three canals we find sensations connected with one dimension. When these sensations are combined the cerebral centers form a perceptual space idea in connection with which all the space perceptions of the other senses in regard to the position of objects and the position of the body are referred. The weak point in the theory of Cyon is that no explanation is offered of the semicircular canals as a mechanism, while the Brown theory is strong in the point that it attempts to explain on a physical basis, the relation of the semicircular canal mechanism to body equilibrium. All the theories seem in a certain degree to explain partially the function of the semicircular canals. Equilibrium including the action of the skeletal muscles in relation to nervous connection as well as the equilibrium in connection with this special mechanism in connection with audition so that the co-ordination of motion is maintained against gravity. This is one of the most important of the body functions. Sensory impressions must be conveyed to the co-ordination centers so as to keep up a close connection between the centers and the different parts of the body. These sensations are called the sense of equilibrium. The muscular sense appreciates muscle tension, the sense of sight appreciates the position of the body in relation to other objects in space, the tactile sensation furnishing the means of appreciating the contiguity of near objects. The air waves act upon the tympanic membrane so that we can appreciate the character of objects that are present. If some of these sensations are lost they may be compensated for by more full development of others; but normally all of these senses concur in providing sensory impulses bearing upon equilibrium. If one of these fails or if there is a conflict in the sensations the result is giddiness, nausea, and some other peculiar feelings. Hence by looking at unstable water untrue impressions of the equilibrium are carried to the brain, producing the tendency to motion with the object of preserving the equilibrium. The sense of equilibrium depends, therefore, upon the action of various sense organs under the controlling influence of the nervous system. There is, however, a special organ for the determination of the position of the head and its movement and hence for the regulation of the entire body. The terminal organ has been localized therefore in connection with the semicircular canals. In the case of the lower animals, chiefly birds, it is found that a disturbance of any of these canals produces (1) at rest an exaggerated position of the head; and (2) as soon as the disturbance is produced there are peculiar movements of the eyes, head and body, the character of these

movements depending upon the extent of lesions in the canals. Hence it may vary from unsteadiness to violent motions of the head and of the body. In the case of a man we find that by placing a person on an elevated surface with the muscular and tactile senses inactive and then causing a movement of the surface the person can determine the motion and its nature as well as the angle of motion. After the sensation of movement there is a sensation of motion in the opposite direction. It has been found that in the case of deaf persons rapid rotation does not produce giddiness. Where we find pathological conditions interfering with the labyrinth there are vertigo signs in co-ordination. Hence it is presumed that a lesion of the semicircular canals produces a change of pressure in the sensory hair cells by an escape of endolymph, producing the sensation of falling in one direction, resulting in an attempt to prevent this imaginary contingency. According to some physiologists the equilibrium that is associated with rest and motion is regulated by the stimulation of different nerve terminals. In regard to the nerve mechanism which regulates the equilibrium of rest, it is claimed that the position of the head while it is in the resting position is associated with the relation of the otoliths in the labyrinth of the ear to the nerve terminals in connection with the maculae of the cristae acusticae. The otoliths are of considerable size in the ears of some of the lower animals like the fishes, so that their pressure upon the hair cells must produce variable sensations and thus give rise to variations in the spatial perceptions.

According to Flourens, the cerebellum is particularly associated with the co-ordination of movement and the maintenance of equilibrium. There is no doubt that the cerebellar integrity is essential to equilibrium, but this does not mean anything more than that the cerebellum represents the center of equilibrium. Animals that have been deprived of the cerebellum seem to be unable to maintain the upright position, and there is also found an unsteady gait as well as peculiar twiching movement of the eyeball. Where the cerebellum is congenitally defective it is found that there is an imperfection in the capacity for walking. The afferent impulses that are associated with equilibration arise from the muscles, the skin, the semicircular canals, the internal ear and the eyes. All of these are closely connected with the cerebellum. There is, as we have seen, a very free communication between the cerebellar gray matter and the entire central nervous system, this representing possibly the close connection of the cerebellum with every possible pathway along which impressions connected with equilibrium may pass. In connection with the muscles we find impressions that are associated with pain, increasing the blood pressure, impulses associated with the extent and the strength of muscular contraction, as well as the localization of the head, the limbs and the other parts of the body, these last two kinds of impulses being associated particularly with equilibrium.

In connection with the skin we find the impulses of pressure and touch at the basis of equilibrium. By rendering insensitive the soles of the feet and covering the eyes the individual would lose the capacity of steadiness. In locomotor ataxia there is a loss of the sensations associated with touch, and hence a disturbance of equilibrium. In the case of a frog, if the cerebral hemispheres are removed, the frog will possess the power of

balancing itself on its limbs, but, if in addition the skin is taken away from the hind limbs it will be unable to maintain equilibrium. That the semicircular canals are associated with equilibrium seems to be undoubted, from the fact that where there is a defect in the internal ear, there is a loss of or impairment to a certain degree of equilibrium. The co-ordination that is necessary to equilibrium is preserved by means of a center in the cerebellum, the center being localized in the middle lobe of the cerebellum, to which sensory impulses pass along the vestibular branch of the auditory nerve from the internal ear. The efferent path may be supposed to be indirect in connection with commissural fibres to the Rolandic motor areas, and thence along the pyramidal tract. The cerebella hemispheres become more important functionally as they become more prominent structurally as we ascend in the scale of animal life. In the fissures, when the semicircular canals are injured, certain involuntary movements are found, which have been called forced movements. By the destruction of the internal ear in the case of the menobranchus the animal is found to wheel around about a longitudinal axis without any control of itself. After a short time the movements cease, but they may be started again by stimulation. In the human subject, by the passage of a galvanic current of electricity between the two mastoid processes it is found that the head tends to turn toward the positive pole. The individual can resist this tendency to turn so long as the current is not very strong, but when it becomes very strong the movement takes place without control. There is no doubt that in this case there is a stimulation of the semicircular canals, and that this is the cause of these forced movements.

SECTION IV. The Sense of Smell.

The sense of smell is located in connection with the mucous lining of the nose, nervous connection being established with the olfactory bulbs. Associated with the walls of the nasal cavity we find turbinated bones which separate each nasal cavity into three meatuses. These lie one over the other, the two higher ones forming the olfactory cavities. This entire osseous structure is covered by the mucous membrane, in which we find imbedded flattened cells to which we find attached the ramifying branches of the olfactory nerve. The mucous lining is not all connected with the sense of smell, but smell is limited to the anterior portion of the superior meatus, the middle meatus and the septum corresponding with these. The rest of the membrane is associated with respiratory action. The membrane that is associated with the movable portion of the nose differs from the membrane that is found in connection with the rest of the nasal cavity. In the vestibular portion the mucous membrane is found to consist of squamous epithelium covering over a tunica propria in which we find papillary eminences. In it we find sebaceous glands and also hair follicles. In the respiratory region we find the membrane consisting of cylindrical ciliated epithelium with some of the goblet cells In connection with the tunica propria we find a number of small racemose glands, some being serous and others mucous in their character. In the olfactory region we find the olfactory epithelium that rests upon a tunica propria. In it we find two kinds of cells, the one in the upper part consisting of

cylindrical cells and the other consisting of protoplasmic cells surrounding a nucleus. The former are called supporting cells having an oval nucleus that projects from the cells, these nuclei when arranged in rows forming the zone of oval nuclei. The latter cells are called olfactory cells, the nucleus being round and the round nuclei being asosciated with the nucleoli, forming in cross sections a zone of rounded nuclei. Associated with the epithelial boundary and the connective tissues we find basal cells consisting of protoplasm and nuclei. The tunica propria consists of connective tissue with some elastic fibres, Bowman's glands being found in the tunica propria. These glands in the human subject represent branched tubes in connection with which there passes through the epithelial layer a duct. These are mucous glands. The olfactory nerve is distributed in the tunica propria, the greater branches having sheaths that spring from the dura mater, consisting of non-medullated fibres, the fibres being distributed into minute filaments ending in the epithelium, connection being established in some way with the olfactory cells. Some claim that the termination is found in connection with the basal cells out of which fibres pass that form connection with the supporting and the olfactory cells. According to this both the supporting and the olfactory cells are associated with the olfactory function. Medullated fibres of the trigeminal are found in connection with the mucous lining of the nasal cavities. To produce the sensation of smell the substances must be in the air or in the form of odors and gases. Substances must be very finely divided, as we find in the case of closing up the nostril with cotton smells are still discernible, although very minute organisms are excluded from the atmosphere admitted. Perfume seems to fill the air and excite the sensation of smell without any appreciable loss of scent. A few grains of musk will perfume a room for years and yet not lose its volume. There are certain gases that have no odor, as hydrogen, oxygen, nitrogen, marsh gas and ammonia. Some of these gases have an irritating effect but have no smell, as in the case of ammonia gas. Gases that have a smell are chlorine, iodine, bromine, arsenic, antimony and sulphur vapors, each of these having its characteristic perfume. The theory has been put forward by Ramsay that smell is due to vibrations of a kindred nature to those giving rise to light. This theory is defended on the ground that to produce smell there must be molecular weight considerably exceeding that of hydrogen. On this basis Ramsay says that odorous substances must be fifteen times the weight of hydrogen. On the basis of this theory it is claimed that the kind of odor depends upon the kind of vibration found among the substances. The sensation of smell may certainly be aroused by vibrations, but the vibrations may be of such a nature as not to produce smell. There is a limit both as to the maximum and the minimum of vibrations necessary to the stimulation of the sense of smell. It is claimed that the particles of odoriferous substance vibrate on the olfactory membrane, producing the mechanical stimulation sufficient to cause sensation. This theory has not yet been proved, but there is no doubt that when odors of flowers are carried on the breeze, particularly in the early morning or in the evening, the air is laden with the perfume. In the case of heavy substances that produce odors, the substances maintain their weight in the air so that the odors continue to produce stimulation. It is for this reason that the air laden with animal odors continues to produce smell sensations

for a considerable period. The air laden with the odor must be brought into contact with the membrane, hence the first thing necessary to the sense of smell is that the person must breathe the air. By breathing the air its odor is brought into contact with the membrane. In order that the contact may produce the sensation of smell the membrane must be moist. The greatest sensation occurs at the beginning of the smell sensation, although the intensity depends upon two other factors, the extent of the membrane affected and the manner in which the odor is concentrated so as to affect the membrane. The sense of smell like the other senses is capable of cultivation to a considerable degree. Where the other centers are deficient or absent smell may become so sensitive as to become the vehicle of considerable knowledge, particularly in regard to the nature of food. If the nasal cavity is filled with water in which is dissolved some odorous substance there is no sensation of smell produced. It is claimed that if a sodium chlorid solution is put into the nasal cavity there is the perception of odor. In some of the lower animals we find the sense of smell developed to a very large extent. It is claimed by some that every individual has some peculiar odor that may be distinguished by him alone. Attempts have been made to classify the different smells but these attempts have been unsuccessful on account of the fact that it is almost impossible to reduce the smell sensations to any primary sensations. We sometimes find subjective smell sensations arising from a subjective irritation in connection with the olfactory mechanism. In the human subjects the sensations of smell are supposed to have an important relation to the sensations of taste, some of the tastes arising from the stimulation associated with the sense of smell. Kant defines smell as "taste at a distance." It is certain that taste and smell are associated together physiologically in connection with our perception of food flavor. When the olfactory nerve becomes paralyzed or is removed the sense of smell is destroyed. Ammonia may stimulate the sensory nerves in connection with the fifth nerve found associated with the mucous membrane of the olfactory region; this odor, however, is not a true smell but depends upon irritation in connection with the sensory surface and the terminal of the sensory branches of the fifth nerve. According to Beaunis the substances which stimulate the olfactory membrane are threefold: (1) Substances acting on the olfactory nerves, as in the case of perfumes which have no pungency or odors which have a pungency; (2) substances whose action is associated with the olfactory nerves and also the nerves of ordinary sensation, as in the case of stimulation by acetic acid; (3) substances that only act on the sensory nerves of ordinary sensation, as in the case of carbonic acid stimulating the terminals of the tactile nerves; (4) some add electrical stimulation which may be produced in connection with the electrode placed upon the mucous membrane which gives a sensation of phosphorus odor.

Smell has been called the ancestral sense on account of the fact that in the primitive brain we find simply a ganglion associated with olfaction. Every substance that we smell produces a particular sensation, although we are unable to distinguish the different odors. It is claimed by some that we can distinguish a number of the individual odors even when the smell is of a mixed nature. This does not enable us, however, to make any distinct classification of smell. In normal circumstances an olfactory sensation re-

quires time to develop when the stimulus has been brought into contact with the olfactory apparatus. The olfactory membrane very soon becomes exhausted. As the surface of the membrane increases in size the sensation increases in intensity, so that in animals whose scent is very acute there is a large olfactory surface. This may depend upon the amount of odoriferous substance brought into contact with the membrane. An olfactometer has been constructed for the purpose of measuring the olfactory sensations, its use being connected with the measurements of the size of the area that is affected by the substance producing the odor. Normally the odoriferous substance passes into the two nostrils so that there are two olfactory impulses. As in the case of vision, however, these impulses are fused together so as to form the single sensation. If two separate odors are brought into contact with the two nostrils we find different results. In some cases there is a variation in the sensation. In other cases one sensation seems to prevail over the other. This seems to indicate that one odor prevails so that the suppression depends upon, not the chemical action of the odor, but upon the action of the central nervous system in giving predominance to one sensation. Our olfactory sensations are associated with the external world by a discriminating process associated with perception. The special relations of the odor are very indefinite, our localization of the position of the odor depending largely upon the movement of the head in the direction in which the strongest sensations seem to take place.

SECTION V. The Sense of Taste.

Taste is associated with the tongue and with the upper portion of the anterior surface of the soft palate and also with the anterior pillar of the fasces. In connection with the sense of taste we find the glosso-pharyngeal nerve, the lingual branch of the fifth and the chorda tympani supplying the papillae on the tongue surface. We find both medullated and non-medullated fibres in the terminals of the glosso-pharyngeal. The medullated fibres freely multiply their branches in the connective tissue and from connections with the taste bulbs which are minute branches in the epithelium. The nonmedullated fibres enter into the layer of epithelium in connection with which they terminate either freely or in the taste buds. These are ovoid bodies which are found imbedded in the layer of epithelium, the one end extending to the upper surface, the other end descending till it rests upon the tunica, the superficial end opening into a minute funnel-shaped canal on the surface called the taste pores. These taste bulbs are found in great abundance and represent the organs of taste. These taste bodies are found to consist of two kinds of epithelial cells, one large and the other small and narrow. The external cells represent the sustentacular structures upon which the taste cells are placed, these taste cells representing the sensory epithelium. In the taste cells we find a nucleus at the middle where the cell becomes thick. In the upper part we find a cylindrical and also a conical part at the upper surface being found a bright substance. In the lower part of the cell we find nodular enlargements in connection with which we find the nerve terminals. The fact that the taste bulbs represent the end organs of taste is proved by the fact that when a substance is brought into contact with these taste bodies

there is the sense of taste. In addition to this we find that these taste bulbs are much more numerous where the sense of taste is acute. If the glasso-pharyngeal is divided these taste bulbs will be generated. In order to the stimulation of the taste sensation in salivation is necessary in connection with the substances that are found in the mouth. Hence, substances must be soluble otherwise they do stimulate taste. If the surface brought into contact with the substance is large then the sensation of taste is increased, the degree of taste depending upon the degree in which the solid substance is concentrated in the soluble form. The dilution of substances with water seems to diminish the sensation of taste, although in some cases as in quinine the dilution requires to be very great. The power of producing the sensation of taste seems to vary with different substances, the substance of a sweet or acid or bitter nature even more difficult to bring within the taste sensation than saline substances. Acid substances are generally characterized by sour tastes, alkalies by a soapy taste, the salts varying from bitter to sweet and the alcohols sweet. The temperature most favorable to the sensation of taste is that ranging from ten to thirty degrees C., either above or below this temperature the action being lessened. Sometimes taste and smell are confused although they are quite distinct. This depends upon habit and education. Taste is capable of extensive cultivation, as is found in the art of testing in which very minute differences may be at once and accurately discerned. Taste may be interrupted by a diseased condition of the tongue. Artificial sensations of taste may be produced by such substances in the blood as morphine, or the bile that is found in jaundice conditions, these producing a sour and unpleasant sensation. On the other hand, those subject to diabetes feel a constant sensation of sweetness, to such an extent in some cases that it seems almost impossible to satisfy the taste. In some cases of insanity there are such tastes developed as are associated with subjective sensation, these tastes arising in connection with the taste centers in the brain. Astringent substances are perceived only by the fore part of the tongue, and bitter only by the back part of the tongue; while sweet and saline substances, although tasted by the whole dorsum of the tongue, are best appreciated by the fore part of the tongue. By chewing the leaves of the gymnoma sylvestre the sensation of taste in connection with sweetness and bitterness is entirely abolished. Much discussion has taken place in connection with the relation of the nerves to the sense of taste. The majority of physiologists are agreed in regarding the glosso-pharyngeal as furnishing the nervous connection for the posterior part of the tongue, while the lingual and the chorda tympani supply the anterior part of the tongue. Taste perceptions, as we have said, are considerably modified by olfactory sensations. This may be shown by the fact that it is almost impossible to distinguish an apple from a pear or a potato if the nasal passages are froze. As in the case of the olfactory sensation the taste sensations increase in tensity as the area is increased to which is applied the gustatory substance. It is in connection with mastication that the complete taste value of substances is determined, this process being completed when, in the act of deglutition, the food substance passes between the tongue and the palate. Taste sensation is at its maximum if the substance is of the same temperature as the body. It has been found that by heating the tongue to fifty degrees C. the taste of sweetness could not

be appreciated. Taste substances seem to come into contact with the sensory endings of the taste nerves when they are dissolved in the salivary fluid of the mouth, and this forms a basis for maintaining a uniform temperature. Taste sensations have been classified primarily into four classes, bitter, sour, sweet and salt, although some have reduced the primary taste sensations to two, bitter and sweet. It is commonly believed that there are nerve fibres corresponding with the four primary sensations, and that the stimulation of one of those fibres gives rise to a particular sensation. This seems to be proved by the fact that different substances are not appreciated as producing the taste sensation at different parts of the tongue. That this is so is proved by the fact that the same substance may produce a different taste sensation at different parts of the tongue. Experiments have been made in which it is found that the different fungiform papillae found in connection with the tongue possess different degrees of sensitiveness in connection with taste sensations. The lymph which is found in connection with the end organs of gustation do not stimulate taste sensation; but by altering the blood composition by introducing foreign substances taste sensation may be produced. By passing a constant current of electricity through the tongue there is developed an acid taste at the positive and an alkaline taste at the negative pole. In connection with taste sensations it is necessary to remember that flavor is not a single sensation but a complex sensation that combines sensation of smell and of taste. These two sensations are often confused, probably because both of the sensations are necessary in order to the stimulation of the flavor sensation. The taste sensation may be said to be intermediate between general and special sensibility. In this sense it is appropriately connected with the perception of flavor. The taste sensibility is not limited to a single nerve but is associated at least with two nerves which furnish sensory impulses in connection with the corresponding part of the organ of taste. This does not mean, however, that the gustatory sensations are limited to general sensibility. A distinction, however, requires to be made between special sensations that are aroused by the sapidity of a substance and the general sensation aroused by the touch and general sensibility. Hence the same substance often stimulates both tactile and gustatory sensations. In this way we have the capacity both from the special and general standpoint of sensibility to perceive flavor.

SECTION VI. *The Sense of Touch and Feeling.*

Of the general condition of the parts and tissues of the body other than the skin we only have a general knowledge in a vague and indefinite way. There is only what is called general feeling, but this condition may under special circumstances pass into a special kind of feeling, as in the case of the feeling of pain. The sense of touch is associated with the skin. Some nerve fibres terminate in very fine fibrils in the epithelium as, for example, in the cornea, in the mucous membrane of the mouth and in the deep epidermal layers. In the epidermal layers we also find cells which are associated with nerve terminals, the cells themselves having long branching processes. We find nerve terminations either in a single but more commonly in a group of cells in connection with which the nerve fibres terminate. These cells

are of different kinds, the simple cells found in connection with the epirdermis; the groups of cells or corpuscles representing two or more cells, larger than the simple cells in connection with which we find touch discs lying between the cells forming the terminals of the nerve fibres. In the case of structures that consist of two such tactile cells we find what are called twin cells, and in the case of more than two we find a group of simple tactile corpuscles. The compound tactile corpuscles found in the capillae of the true skin are particularly associated with the palm of the hand and the sole of the foot. Around about these corpuscles we find nerve fibres in spiral form, the corpuscles themselves being composed of flattened cells. A peculiar kind of these corpuscles has been called the end knobs of Krause, consisting of a number of cells, in the midst of which we find nerve fibres, the whole group of cells being joined together by connective tissue. These corpuscles are found in connection with the conjunctiva and in the mucous membrane of the clitoris. In addition to these we find the end bulb both of a simple and a compound nature, these being elongated, oval bodies, a nerve fibre entering into the one end of these bodies. The simple bulb consists of a modified nerve terminal, an internal knob being found in connection with the glanular substance, the knob being a continuation of the white substance of the nerve fibre. At the central part we find the axis cylinder, which enters the lower part of the knob and passes through it and terminates at the upper end. These end bulbs are found in connection with the conjunctiva and the mucous membrane of the mouth. The compound end bulb forms the corpuscles of Pacini, being elongated bodies consisting of an external part, an internal knob and an axis cylinder. These Pacinian corpuscles are found in the connective tissue of the sole of the foot and the palm of the hand and also in the connective tissue of the deep parts of the joints in the mesentery and the pancreas as well as on the penis and clitoris. Touch is a sensation associated with pressure in connection with the external surface of the body. Some call it a sensation of simple contact, but even in the most delicate contact there is a certain amount of pressure. There is no contact without some slight pressure. The pressure may become greater, and in that case there is a feeling of resistance. If the resistance becomes great it becomes muscular; hence by the muscular sense is meant the indefinite sensation by which the state of the muscles and the amount of concentration necessary to produce any particular movements are determined. Our movements are guided, partly, at least, by the sense of touch and partly by visual and other sensations. If this pressure becomes excessive then we have the feeling of pain. The organs that are associated with touch are characteristically mobile, as, for example, the fingers of the human subject. Tactile sensation, as it is associated with the soles of the feet, is very important in connection with steadiness in standing and walking. By means of touch we are able to appreciate mechanical stimulation and force. From the skin we may have general sensations, for example those produced by the passage of an electric current. By the stimulation of the special sense organs we get special sensation of contact pressure and temperature. What is true of the skin is true also of the various mucous membranes for a short distance from the various orifices that open on the external surface. The intensity of sensitiveness is determined by discovering the shortest distance at which two points of a pair of compasses may be felt. Tabulated results

have been made out to mark the sensitiveness of the different parts of the body in the case of an adult, for example, the tip of the tongue is represented by 1.1 mm. The tip of the nose 6.8 mm., the center of the palm of the hand 8.9, forehead 22.6 mm., the forearm and leg 45.1 mm., and the upper part of the arm, the thigh and the central part of the back 67.7 mm. Not only is the skin very sensitive, but the exact location of the sensitive sensation can be localized. This localization of sensitiveness depends upon the number of the nerve fibres. For example, by comparing the tip of the finger with the back of the hand. It was at one time supposed that sensitiveness was improved by exercise. It has been found, however, that continued exercise d)es not necessarily improve sensitiveness. The sense of absolute sensitiveness depends upon a number of conditions and particularly upon the sense of pressure, determining the intensity of the sensation. This sense of pressure may continue before the mind for some time after the cause producing the sensation has passed away, and this forms the basis of the comparison of different impresssions. The localization of the part touched is determined giving us the means of determining the position of the body brought into contact with the object. By touching the body at different points, by comparing the differing pressures and estimating the various points in space occupied by the body in contact with the object the shape of the object may be determined. In this way there is constructed a tactile field in which we find tactile pictures, those pictures occupying a definite position in the field. When the hand or fingers are passed over the body there is brought into contact with the fingers there is formed a number of tactile pictures so that by means of these a perception is formed in regard to the shape and the size of the object. If there is anything abnormal in the development of the body or in its position then there may be formed a false conception of the object and of its shape.

The commonly accepted theory of touch is that developed by Weber and Lotze. It is based upon the supposition that, although every tactile sensation is referred to a certain part of the tactile field it is to be referred to a circular region of the skin named the circle of sensibility. If two of these circles of sensation overlap each other then they cannot be separately perceived. Each of these circles is supplied by a single nerve. These circles of sensibility vary in size in different parts of the body,'the area of distribution depending, to some extent, upon the innervation of the different parts of the body. The skin has been regarded as the localized region in which from an anatomical standpoint these tactile sensations exist. We must remember, however, that the action of the nerve fibres and nerve centers is of considerable importance in determining the sense of touch. In the nerve centers we find an irradiation of impulses and it is impossible that when the impulse passes to the brain from a localized cutaneous area there may be a diffusion to contiguous cells with the result that by exciting these cells the sensations are referred to the peripheral origin in connection with some cutaneous regions. The sensations of temperature are also localized in the skin. This rests upon stimulation by heat applied to the terminal organs. By dipping the elbow into ice water cold is experienced at the elbow and pain is felt at the points of the fingers in which are localized the terminals of the ulna nerve. If any portion of the skin is above its normal temperature

there is heat felt, while if the opposite is true cold is felt. The normal body temperature at any part of the body depends upon the amount of blood that passes through that portion of the body. If the body comes into close contact with a good heat conductor cold sensations are felt because of the removal of heat of the body. If heat is borne to the body by a good heat conductor then the temperature is raised. All parts of the surface are not equally sensitive to the pressure and the temperature. Thus the palmar aspect of the fingers appreciates pressure much more delicately than the surface of the arm. The parts of the skin most sensitive to temperature are the cheeks, the eyelids, etc. It would seem that the appreciation of pressure is heightened by contact, for if the finger is dipped into mercury the pressure is felt especially at a ring at the surface of the fluid. Two points close together in contact with the skin are felt at one point but the distance between the points necessary to produce this result varies widely in different situations. On the tip of the finger or of the tongue the two points must be very close together to be felt at a single point, while on the front a considerable distance may separate the two points yet the person supposes that only one is touching him.

It has been suggested that the temperature acts on a nerve fibre terminating in the corpuscles of the epidermis, that contact stimulates the nerve fibres of the touch corpuscles and that through the Pacinian bodies pressure is appreciated. When the skin temperature varies from fifteen to thirty-five degrees C. the tips of the fingers can appreciate a varying temperature of from 20 to 30 degrees C. There is a variation in the sense of temperature in the different parts of the body, the tongue tip, the eyelids, the cheeks and the lips. Heat and cold sensations vary in alternation. If the body is dipped into water from eight to ten degrees cold is felt; if afterwards it is dipped into water from fifteen to eighteen degrees then there is a feeling of warmth succeeded by cold sensation. It is said by recent experimenters that along the surface of the skin there are small regions which are more sensitive to cold and heat than other points, these minute areas being called temperature spots. These small areas are said to be associated with hairs found in the different parts of the body. Among these have been localized cold spots and warm spots, the cold spots being more numerous than the warm spots. The excitation of these points produces the sensation of cold and heat, but not of pressure. There is no terminal organ associated with the temperature sensations.

In addition to the sensations of pressure and temperature we find the pain sensations. Pain is produced not by stimulation of the terminal organs or any particular organ, but by the overstimulation of any of the sensory fibres. These impulses of pain pass along the sensory fibres and along the special paths in the spinal column to the brain. The irritation of a sensory fibre may produce pain, and if the irritation is so strong as to destroy the normal function of the nerve there will be a resulting painful sensation. It is not possible to always localize pain. This may be due to the principal of irritation among the different nerve centers, the pains being often felt in the regions entirely different from the localization of these sensations. The intensity of pain depends upon the intensity of the irritation of the sensory fibres, while the extent of the pain depends upon the number of nerve fibres that are affected, the quality of the pain being

determined by the kind of irritation and the part affected, as well as the extent and the continuance of the pressure. Burning, pressing, biting, or any of these acute sensations represent pain or the excessive stimulation of certain sensory regions. Pain has been spoken of as "the prayer of a nerve for pure blood." This is true physiologically within certain limits. Pain in general indicates that something has gone astray in the body mechanism, the freedom from pain being the indication of the normal condition of the body in health. Hence, physiologically, pain indicates something abnormal, pointing out the seat of some abnormal action, and in some cases indicating physiological rest for the purpose of repairing the tissues. It is not definitely settled whether the sensory fibres associated with painful sensations are distinct from the fibres of the tactile sensation. There seems to be some evidence, both physiological and pathological, in favor of some certain distinctions, especially in the fact that the pathway for painful impulses in the spinal cord is different from that in the ordinary tactile sensations. In addition to this in certain diseases there is a loss of the sensibility of pain, without any loss of the tactile sensations. The consensus of opinion among physiologists is that pain depends upon an overstimulation either of the nerves of special sense or of some of the general sense nerves. According to Prus there are nerve fibres associated with the sheaths of the nerve trunk whose irritation produces painful conditions associated with neuralgiac conditions. These fibres he found microscopically, and to them he gave the name nervi nervorum periphericorum.

All of the cutaneous conditions depend for stimulation on some form of cutaneous energy, these including the touch sensations, temperature sensations, presssure sensations and sensations of pain. Muscular sensation gives us an appreciation of the intensity as well as the direction of muscular action. In connection with this muscular sense there is a general sensibility in connection with which we perceive the position of our bodies at rest. External objects, their size and distance from the body, are perceived by sight and hearing. This knowledge however depends upon judgment in regard to the meaning of auditory and visual perceptions so that they are interpreted in connection with the muscular sensation. Our knowledge therefore of the external world depends essentially upon muscular and tactile sensations, because all the other sense perceptions depend upon these for correction and interpretation. The education of the mind in regard to the external world consists in the collection and harmonizing the different perceptions gained from audition and vision with the sense perceptions depending upon the tactile and muscular sensations. As soon as a sensation is felt there is a muscular movement of some kind which gives us definite knowledge of the nature of the sensation. Hence the physiological basis of our sense knowledge depends upon sensations aroused by external objects in connection with the muscular sense. Some of the tactile sensations such as hardness represent complicated judgments based upon the combination of tactile temperature and muscular sensations. In its anologies the tactile sensation is really the sensation of pressure upon the cutaneous surface. In order to test the sensibility of the skin in relation to pressure the hand or the skin surface must be brought into contact with the object and subjected to pressure in this contact with the object. Attempts have been made to distinguish differences in pressure by finding out the minimum increase necessary to be added to a

weight in order to perceive increase of weight. Weber has formulated a law in regard to the relation of stimulus and sensation, as follows: the stimulus that is necessary to produce a perceptible increase in sensation is always in direct proportion to the amount of the stimulus that is already applied. Fechner expressed the same idea in his psycho-physical principle that the intensity of the sensation varies with the logarithm of a stimulus, that is, the sensation increases in arithmetical proportion while the stimulus increases in geometrical proportion. On the basis of this law it has been found that the forehead and the lips can appreciate one-fortieth of the weight while the skin of the head and of the fingers requires an increase of one-twentieth in order to appreciate the increase. This indicates that there is a difference in the degree of tactility in the action with different parts of the body. In order to test two weights it is necessary that they should press upon equal areas of the skin so that if two weights that are equal different size the one that touches the larger area will seem to be heavier, because it stimulates the larger number of nerve fibres. This, however, has not been demonstrated, although Weber claims that it is true. When a tactile sensation is felt the sensation is referred by the mind to a particular portion of the body surface and the sensation is localized in that area. In connection with these peripheral areas we find the nerve fibres, and some claim that there are nerve cells in the brain corresponding with each of these minute areas. This, however, is not necessary, because it is only by education that a sensation is localized as being associated with a particular peripheral area. According to Lotze each of the cutaneous areas comes to possess a local sign which forms the basis of the conscious recognition of peripheral stimulation at a particular point. These tactile areas are circular or oval in form, having a long axis. The tactile sense is fundamentally based upon pressure, and hence the skin surface has been mapped out into areas corresponding with points of pressure, these points being marked by the termination of the pressure nerve fibres. This tactile or pressure sense is a special sense, as the stimulation passing from these local points to the nerve centers gives origin to the tactile feeling or sensation. The peripheral terminal of the pressure fibre becomes modified under the influence of certain stimulations so that they become specialized in connection with particular stimuli. As we have seen the skin is also the organ associated with the perception of changes of temperature. This perception in all probability takes place on account of particular stimulations imparted to the skin by the raising or lowering of the temperature thus stimulating the terminal parts of the temperature nerves. These temperature nerves and their terminals in connection with the cold and hot spots represent specific nerves or nerves of special sense. In addition to these special tactile senses of pressure and temperature we have associated with the skin a common or general sensation. This points out the consciousness that we have of the position of the different parts of our bodies and their condition at the time. Even in the absence of the special sensations we can understand and appreciate our body position. According to this the nerves of common sensation are all the time active in bearing impulses to the sensorium in regard to the position and condition of the different parts of the body and possibly in connection with the equilibrium of the body. Pain as we have seen

represents the overstimulation of these nerves of common sensation. Among these common sensations have been classified sensations of hunger, thirst, shivering, fatigue, etc. All of these sensations are subjective and not particularly localized in connection with the body. In close connection with this common sensation, possibly forming a part of it, is what is called the muscular sense. This muscular sense refers to the sensation of pressure, involving both pressure and resistance to pressure in connection with muscular movements. This may consist of a perception of voluntary activity to perform a definite movement, or it may arise from the action of a number of muscles which are in activity. Through the muscular sense the brain centers may receive sensations resulting in information regarding the activity of contraction; the amount of the contraction upon which we estimate the character of the movements; the rapidity with which the contraction takes place; and the time during which the contraction lasts, as well as the position occupied by the body and its different members. The sensation of the direction of movements is very complicated, depending upon visual, muscular and tactile sensations. There is also associated, in part at least, with the muscular sense, the feeling of equilibrium which is necessary in connection with locomotion, whether of the body or the movement of the members of the body. Hence the direction of these movements concerned in the motion of the body or the movement of its parts depends upon the sensations of pressure resistance and also the visual and tactile sensations. In the case of paralysis, as in locomotor ataxia, the only guide is the sense of vision directed to the feet and when this is interfered with there is a lack of the direction of movement resulting in unsteadiness. By the sensory nerves of the muscles impulses are carried to the brain centers arousing sensations of muscular resistance. Several theories have been propounded to account for this sense commonly called the muscular sense: (1) that we estimate the muscular conditions from the efforts that are necessary to produce a certain contraction, in other words, there is a perception simply of the volition to produce a certain act and not what follows the volition, the active effort to produce the act or the motion. (2) That the muscular sensation arises directly from the irritation of nerves on the surface of the skin or the membranes that cover the muscles. (3) That there are special muscular sense fibres connected with the muscles which carry the impulses thus originated directly to the brain centers. To compare weights for example pressure upon the skin is not sufficient; there must be a lifting of the objects, indicating that there is a certain amount of muscle tension and that a definite resistance is necessary against which the muscle contraction takes place. This seems to indicate that when the muscles contract there is an impulse or a series of impulses passing to the brain indicating the amount of tension and resistance, the nerves in this case being possibly connected with the tendon in which the muscle rather than in the muscle itself. Several physiologists have localized groups of muscle fibres at the origin of the tendons in connection with the muscles and particularly at the joints. All voluntary movements of the muscles are associated with a particular sensation of effort depending upon the extent of the contraction. Some claim that the muscular sense is not dependent upon sensory impulses, but that the nerve centers simply send out voluntary impulses, determined by the amount of nerve force that is sent out. This, however, does not prove that

the brain is not kept in touch with the active muscles by means of impulses passing to it along afferent paths. There is no doubt that a keen perception of muscle tension exists and that this determines the amount of resistance that is associated with the contraction of the muscles. This perception may depend upon an immediate consciousness of the amount of nerve force that is sent out from the nerve centers, but it is also associated with the income of sensory impulses indicating the muscle tension. According to Golgi, there are two kinds of nerve terminals in connection with tendons and the union of tendon and muscle. According to Sterrington, there are terminals found in connection with the union of muscle and tendon, which he calls muscle spindles. According to this, the fibres that are found in connection with the muscle are largely sensory in their functions. It is in connection with these muscular sensations that we come to appreciate, from the standpoint of perception, the size, form and position of objects. This muscular sense also furnishes the means of interpreting and verifying the sensations that originate in connection with the other senses. It is in connection with this muscular sense that our spatial perceptions, as well as the time relations of the mental phenomena, are perceived. The muscles, even when not subjected to effort, are in a condition of tonicity, this tone depending upon reflex stimulation in connection with the muscular sense. In regard to the nature of the afferent impulses which give rise to this sense of effort or muscular sense we find that the impulses as well as the pathway along which they pass is complicated. There are muscle changes represented by the contractile movements, there are cutaneous variations and also locomotor variations, all of these together with the articular movements of joints, ligaments and tendons which may possibly give rise to the different impulses. There is no doubt that the skin is one of the sources of these sensations in connection with pressure and temperature. Some claim that these sense impulses gives rise to the entire muscular sensations. This, however, seems to be erroneous. The afferent impulses are the essential to co-ordinated movements, all of the body movements being guided to a very large extent by these efferent impulses. These co-ordinated movements it is true that these co-ordinated movements may be preserved even when the skin and the skin sensations are absent. Yet there are cases on record in which we find the absence of co-ordination accompanied by the absence of the muscular sense. Hence these simple cutaneous sensations are not essential parts of the muscular sense. The sense of effort or of fatigue determine the muscular sense to a large extent in the muscles, the joints, the ligaments and the tendons. There is no doubt that the joints and the muscles do furnish afferent impulses for there are sensory fibres in connection with these. The knee jerk is an example of a purely muscle reflex in connection with the impulses passed from the muscle. The muscular sense is thus based upon impulses that originate from the muscles, the tendons and the joints.

SECTION VII.—The Special Muscular Mechanisms, Voice and Speech.

The voice results from vibrations of the vocal cords, the two bands of elastic tissue that are found in the larynx. We must distinguish voice from speech, which represents a specialization of vocal sounds, to express ideas. We find vocal sounds in some of the lower animals which do not possess the faculty of speech. It is possible that speech may be found without real sounds, as in the signs which are made use of as a means of communicating ideas. The vocal organ is in the human subject in the upper part of the neck, forming a characteristic prominence. There is an opening above into the pharynx and below into the trachea. It is composed of a cartilaginous framework united by means of elastic ligaments, two of these forming the true vocal cords. The arrangement of muscles is such as to move the cartilages upon each other so as to regulate the position of the cords. The air is passed through the trachea from the lungs during expiration. The whole arrangement represents a minutely formed sounding apparatus, the lungs forming the wind-bag and the trachea the passage for the wind from this bag to the sounding apparatus in the larynx. If two fine elastic ligaments were stretched across the open end of a wide glass tube having a narrow opening between the edges of the ligaments, and if by means of a wind-bellows a strong current of air is passed through the tube the air pressure in passing through the ligaments would force open the edges, these margins springing back again when the pressure is withdrawn. If these were produced in rapid succession then vibrations of the margins would follow sufficiently strong to produce a musical tone or tones. In this case, by the condensation of the air, sounds are produced. The intensity of the sound would depend upon the variations of the ligaments and the pitch would depend upon the variation in the tension as well as the amount and force of the air; the larger the amplitude of the vibrations the greater the elastic tension of the ligaments. These cartilages form the laryngeal framework in the mechanism of speech. These cartilages are connected together by means of ligaments; the special mechanism of vocal utterance consisting of the inferior thyro-arytenoid ligaments called the true vocal cords. They consist of delicate elastic fibres with posterior attachment to the anterior projection of the base of the arytenoid cartilages, and with anterior attachment to the middle angle between the laminae of the thyroid cartilage. They continue the lateral crico-thyroid ligaments. The rima glottidis divides the laryngeal cavity into an upper and lower part between the two vocal cords. Above these vocal cords and between them and the false vocal cord we find a sac called the ventricle of Morgagni, from each ventricle opening a smaller pouch called the laryngeal pouch extending between the superior vocal cords anteriorly and the thyroid cartilage exteriorly, extending up to the upper margin of the thyroid cartilage beside the epiglottis. The ventricles allow of the free vibrations of the true vocal cords in connection with the passage of air. The upper glottidean opening is triangular in shape, the narrow part being posterior and the wide part anterior. It is bounded anteriorly by the epiglottis, posteriorly by the tops of the arytenoid cartilages, and laterally by the arytenoid-epiglottidean folds. The glottis viewed in connection with the laryngoscope appears as a long narrow fissure on each side bounded by the true vocal cords above which are the false vocal cords, the ventricle opening between them. The rima glottidis in the normal adult male is about 23 mm. from the front backward and six to ten mm. transversely. In females and males before they

reach puberty the antero-posterior diameter is about 16 mm. and the transverse diameter four to five mm. The muscles brought into play in connection with the vibration of the true vocal cords are the sterno-hyoid and the omo-hyoid, the sterno-thyroid and the thyro-hyoid, that move the entire larynx; and the intrinsic muscles that move the cartilages, the crico-thyroid, the posterior crico-arytenoid, the lateral crico-arytenoid, the thyro-arytenoid, the arytenoid and the aryteno-epiglottidean. The crico-thyroid is a short triangular muscle passing from the cricoid to the thyroid cartilages. By the contraction of this muscle these two cartilages are brought close together, the thyroid being fixed by the intrinsic muscles so that the anterior margin of the cricoid is elevated and its posterior margin is depressed so that the true vocal cords are distended. The thyro-arytenoid has two parts, the external and the internal. Some of the fibres of the anterior part extend from the thyroid cartilage concavely to the vocal process which is found at the base of the arytenoid cartilage, so that they form a parallel with the true vocal cords pulling forward the arytenoids on contraction and relaxing the vocal cords. In this way the crico-thyroids and the thyro-arytenoids represent antagonistic actions. Some fibres also originate laterally in connection with the cord and extend obliquely to the vocal process, tightening the cord in front and relaxing the cord behind their attachment. Other fibres project the margin of the cord, and still other fibres produce the rotation of the arytenoid in a direction outward, while others aid in pushing downwards the epiglottis. The posterior and lateral crico-arytenoids act in opposition to one another. The posterior originates from the posterior part of the cricoid cartilage extending to the base of the arytenoid; the lateral originates from the upper part of the cricoid extending to the base of the arytenoid. The arytenoid cartilages are pyramidal in shape, at the inner angle of the triangular base being found the true vocal cords and at the outer angle the posterior and lateral crico-arytenoid muscles. By the posterior crico-arytenoid there is a rotation of the vocal processes from the inner to the outer and a widening of the rima glottidis, whereas the lateral crico-arytenoids rotate the vocal processes from the outer to the inner and bring the vocal cords together. The arytenoid muscles are found to pass from the one arytenoid cartilage to the other with the result that in the action of the muscles the cartilages are brought together. The aryteno-epiglottidean muscles originate close to the external angle of the arytenoid, the fibres passing in a slanting direction towards the outer and upper margin of the antagonistic cartilage. These muscles aid in approximating the arytenoids, pulling down the epiglottis and assisting in the closure of the upper laryngeal opening. In connection with the elastic action of these muscles the vocal cords become relaxed.

The intensity of vocal sounds is dependent upon the extent of the movements of the vocal cords. The pitch is dependent on the number of the vibrations in a given time, the number of vibrations depending on the length, the size and the amount of tension in connection with the cord. The higher pitch depends on the greater tension and the lower pitch upon the greater length of the cords. The human voice naturally extends to about three octaves. In the male the cords are larger than in the female, producing a lower pitch of greater strength. At the period of puberty there is a rapid development of the larynx, the larynx changing in connection with the change of voice. This change is different in the male and female, being much less in the female than in the male. In the female the glottis increases at puberty about one-third in size, whereas in the male the increase is about two-thirds. The male larynx is

greater than the female by about one-third. In old age the higher notes become indistinct, and gradually weaker, the voice changing in its character as the elasticity is lost, due to the ossification of the cartilages beginning in the thyroid and then extending to the cricoid and arytenoid. The quality of the vocal sounds of the voice is regulated by the same laws that govern the quality of musical tones in the case of an instrument. In a high pitched note the cords are tense, close together and vibrate at their margins only. In producing a low pitched note the cords are more lax, further apart, and vibrate throughout their entire breadth. These different positions and degrees of tension of the cords are produced by contraction of the different muscles of the larynx. The range of any individual voice is determined by the length of the vocal cords, the longer the cord the lower being the pitch of the voice. Hence in the adult male the vocal cords being longer, the voice is deeper than in the case of women and children. The longer an individual makes his vocal cords at any particular moment the higher the pitch of the note produced, because here the lengthening of the cord means the making of the cord more tense. The quality is determined by the various cavities placed above the cords which act as resonators. These are the ventricles of the larynx, the pharynx, the nasal fossae, the frontal, sphenoidal and maxillary sinuses. As the entrances to these become smaller or obliterated in old age, the voice loses its fullness and becomes characteristically squeaky. The voice is thus produced by means of the vibration of the true vocal cords in connection with the passage between them of expired air while they are brought together and held in a condition of tension by muscular action. The simple vibration of the cords would not produce a strong sound, hence the intensity of the voice depends upon the force of the expired air and the action of the resonating cavities that lie above and below the vocal cords. It is claimed by some that the epiglottis discharges an important function in the modification of vocal sound as it is found to cover the opening in connection with the vibration of the air. The epiglottis is said to act as a sounding board in forcing the vibrations of the air as these come into contact with it. From each of the margins of the epiglottis there is the mucous membrane passing downward and backward which constitutes the lateral rim of the superior laryngeal opening terminating in the arytenoid cartilages. There is a rounded projection on the posterior edge of this mucous fold consisting of the Santorini cartilage and another prominence outside of it called the Wrisberg cartilage. The false vocal cords originate from the thyroid cartilage and find insertion in the arytenoid cartilages, their free margin being ligamentous. They approximate in connection with the action of the laryngeal sphincter muscles, forming protection for the glottis. It is claimed that when the true vocal cords are paralyzed these false vocal cords vibrate and may be substituted in connection with vocalization for the true vocal cords. By the combined action of all the muscles except the crico-thyroid and the posterior crico-arytenoids we find the laryngeal sphincter action. By the action of the oblique and transverse arytenoid the vocal cords are brought together and the glottis constricted by the aid of the external thyro-arytenoids and the lateral crico-arytenoids. By the action of the posterior crico-arytenoid the vocal cords are separated and the glottis enlarged. By the contraction of the crico-thyroids the vocal cords become tightened, whereas they become relaxed in connection with sphincter action, particularly the action of the external thyro-arytenoid muscles. Thus it will be seen that the combined action of different muscles is required in connection with vocalization. The nerve-supply to the larynx is derived from the superior and inferior laryngeal

nerves. The very delicate surface of the mucous membrane above the vocal cords receive sensory fibres from the superior laryngeal. Motor fibres are supplied to the crico-thyroid by the superior laryngeal, motor action being very essential in connection with the tightening of the vocal cords. The inferior laryngeal supplies motor fibres to the other muscles of the larynx. The vocal apparatus is thus found to consist of the air, which is associated with motive action; the larynx, in connection with which we find vocal tone; the pharynx, the thorax, the mouth and nasal passages, in connection with which the tone is varied, and the organs that are associated with speech or definite articulation. Vocalization is produced by the vocal cord vibration, the vocal cords having been brought together and rendered tense in connection with the neuromuscular mechanism. When this is accomplished the expiration of air presses against the vocal cords producing a separation and a resulting vibration of the cord.

In connection with vocalization we must distinguish (1) the loudness of the vocal tone. This depends upon the amount of air in relation to the extent of the vibration as well as the force with which the expulsion of the air takes place. It also depends on the resonating action of the true cavities in connection with which we find the vocal cords, namely the thorax and the resonating cavities of the head, the resonating action intensifying the vibratory force. (2) The vocal pitch depends upon the length, the tightness and the thickness of the vocal cords. These are regulated by muscular action. (3) The quality of the vocalization depends upon the complex character of the vibrations that take place in connection with the vocal cords. On account of the large number of varying elements in the mechanism great variation in quality is possible, depending upon variations in the resonators as well as in the vocal cords themselves. The muscles possess a remarkable degree of adaptation, modifying the pitch and quality of the vocal tone. This is due perhaps largely to the nervous mechanism that is brought into close connection with the different muscles. The vocal cords are in a condition normally of tension, so that variations in the pitch of their notes is possible, the pitch being raised by the contraction of the crico-thyroid muscle. This does not account for the possible change of pitch in connection with the voice. By the contraction of the arytenoid and crico-arytenoid muscles the vocal processes are brought closer together with the result that their vibration is impossible. Vocalization must thus be confined to the vocal cords, the tension force of the crico-thyroid depending upon the action of the glottis. The vocal cords may also be shortened by the contraction of the thyro-arytenoid muscles, this involving a variation in the vibratory rate. When this contraction has attained its maximum the muscle relaxes again to begin contraction after the shortening of the vibratory portions of the glottis. In this way we find several adaptations in connection with the laryngeal vibrating mechanism, each variation involving a variation in pitch, this pitch variation being capable of still further variation in connection with the crico-thyroid muscle. It is found in connection with vocalization that with variations in quality and in pitch there are several breaks in the ascension of the musical scale. These breaks mark what is called vocal registration, the range of vocalization being determined by the extent of this registration. According to the most generally accepted opinion there are three such variations, the lowest being called the chest voice, the middle being called falsetto and the highest being called head vocalization. The chest voice is characterized by strong vibrations in connection with the thoracic walls. In passing to the middle and the higher scale thoracic vibration is lessened and gives place to the vibrations of the bones of the head. Madam Seeiler dis-

tinguishes five different conditions: the chest voice, a second chest voice, a first and second falsetto voice and a head voice. According to her in the chest voice the vocal ligaments and the vocal processes are in vibration. In the falsetto voice the vocal processes are closely bound together, the margins of the ligaments being in vibration. In the head voice there is a deadening of the ligamentous vibration, only the margins of the ligaments at the anterior extremities being in vibration. Ordinarily voices are classified according to the elasticity of the laryngeal parts of the mechanism and the resonating action. On this basis we find commonly four classifications of voices, the bass, the tenor, the alto and the soprano. Speech is the production of particular sounds to express certain ideas. The various vowel sounds are produced by varying the shape of the buccal cavity and of the aperture of the mouth through which the air escapes. Consonants are sounded by placing obstacles of different kinds at different places in the way of the current of the air. Thus we speak of labials, dentals, gutturals, etc. The production of voice or formation depends, therefore, upon the vocal cords. Musical tones depend upon the vibration of the true vocal cords. These notes are called either pure or mixed notes, being made stronger by the air resonants in connection with the air passages and in the cavities of the pharynx and the larynx. In the case of the mixed notes where there is a combination of small or less perfect notes, some of these are strengthened by the resonance of the cavities above the vocal cords. This may be carried to such an extent as to obscure the real note and to produce an entirely different quality of note. Helmholtz has pointed out that certain modifications of the buccal cavity gave to vowel tones a peculiar pitch so that each vowel has its own definite pitch. Thus the quality of the note depends upon two things: (1) The length, elasticity and vibration of the vocal cords; and (2) the action of the resonating cavities of the mouth and pharynx. In vocal music the tone seems to come at times from the throat, at other times from the thoracic cavity and from the head, and the notes are termed chest, falsetto, head notes. There is much difference of opinion among musical schools as to the language used in the description of these varying registers of sound. The older Italians spoke of three conditions called petto, gola and testa, while the French commonly speak of two registers, the thorax and the head. These variations however do not imply any marked physiological variation in the vocal mechanism.

By the use of the laryngoscope the variations in the vocal apparatus can be examined. It is a small mirror about the size of a quarter attached to a large handle at an angle of about 130 degrees. It is put into the back part of the throat so that the light can be thrown upon it, the light being reflected upon the glottis, their reflection being passed back from the mirror and then upon the eye. During normal quiet breathing the glottis is shaped like a lance between the cords. By a deep inspiration the glottis is thrown wide open. When there is to be vocalization the vocal cords come close together either along their entire length or along the length of the ligamentous cord, the space between the arytenoids being open. At the beginning of the sound the glottis is opened, the nature of the opening determining the nature of the vocal utterance. While the thoracic sounds are produced the space between the arytenoid cartilages is open, the space between the vocal cords assuming the form of an elliptical opening, this opening being lessened as the sound increases in pitch. In the production of the head voice the opening between the arytenoid cartilages is closed and between the vocal cords is wide open, permitting the free passage of air. In the falsetto voice the vocal cords vibrate at their margins, chiefly at the middle,

vibration at the other parts being prevented by the pressure of the false vocal cords. Some think that in falsetto the vocal cords vibrate in their full length, forming lines parallel to the free margins of vibration. Others think that it is produced in the same way as the whistling sound.

Voice is thus a modification of sound, this modification taking place in connection with the physiological structure of the vocal apparatus. From the standpoint of speech language is found to consist of a termination of certain musical sounds, the vowels and consonants in the production of which we find the vibration of the vocal cords in addition to certain forms of obstruction in connection with the action of different parts of the mouth. In connection with the vowel sounds we find syllable accentuation, whereas in the consonants we find sounds that are produced by peculiar impediments. Articulation represents a modified speech in connection with the action of the lips, the tongue, the palate and the jaws. Articulation is employed to express ideas. Distinct articulation is dependent upon carefully adjusted muscular movements found in connection with sonation. Vocalization is sometimes distinguished into oral or spoken language and musical or singing language, the former kind of language being articulated in connection with the mouth, while the latter represents modification in the quality of the sound taking place in the mouth. Vowel sounds are associated with the vibration of the vocal cords, the quality of the vowel sound being determined by resonance in connection with the cavities that are found above these vocal cords. In the articulation of the vowels we find that there is a variation in the cavity of the mouth, an alteration in the position of the tongue and the soft palate. According to Helmholtz the vowel sounds differ in quality on account of the varying nature of the resonance in the cavity of the mouth and also depending upon the shape of the cavity of the mouth, the varying shape producing variations in the overtone. This depends upon the fact that if the mouth is placed in position to form the various vowel sounds there is a variation in the pitch of the primary note and also a variation in the vibratory rate. As the shape of the mouth changes we find variations in resonance. In the case of vowels whose normal pitch is low down it is found that they cannot be sounded without difficulty in the upper musical scales: the same thing is true conversely of vowels whose normal pitch is high, that they cannot be sounded without difficulty in the lower musical scale. Hence articulate language in speech is very much more distinct than that in music. The cavity of the mouth has a definite pitch for different vowel sounds, hence if the same vowel is vocalized in connection with different functions of the musical scale there is no change in the tones whose strength depends upon resonance although there is a difference in the primary note. In this respect vocal resonance is entirely different from instrumental resonance. In addition to this it has been found that the force of the upper partials in connection with the vowel sounds is dependent upon the force with which they are produced by the vocal cords. Hence vowel quality depends upon the vibratory action of the upper partials and the position occupied by these upper partials in relation to the primary note. Hence the human voice is capable of adjustment and adaptation such as cannot be found in connection with a musical instrument. In connection with whispering we find vibratory action associated with musical notes giving place to noises. The glottis is open and the vocal cords are relaxed. Vibrations are found in the larynx and in the mouth cavity. In whispering vocalization may take place that is vowel in its nature on account of this many vibrations that are found in connection with the position of the mouth. Consonantal vocalization differs

from vowel vocalization in the fact that vowel vocalization takes place in connection with the vibration of the vocal cords, the vibrations being modified by the resonating action of the cavities above the vocal cord. In the case of the consonants the sounds are formed in connection with the buccal cavity, intensification of the sound taking place in connection with the laryngeal action. In forming the consonants there is a modification of the mouth cavity either by narrowing it or by closing or opening the air passage so that a characteristic sound is uttered. The supra-laryngeal parts are the portions of the speech mechanism that produce the consonant, while the vowels can only be modified by them. No absolute distinction can be drawn between the vowels and the consonant on account of the fact that variations in formation and expression may give us the transition from the one to the other. Three particular articular regions have been vocalized, the guttural in connection with the soft palate and the base of the tongue; the lingual in connection with the tongue and the hard palate; the labial in connection with the lips.

It is claimed that in the formation of the consonants several different processes may be traced out: (1) a contraction takes place in the guttural, lingual and labial parts of the vocal mechanism by means of which in connection with the expiration of air we have the vocalization of such consonants as ch and j among the gutturals, s among the linguals, v and f among the labials. (2) The perfectly sudden closing of the articular region in connection with which sound is produced either before the closing or just at the transition from closing to opening gives us g and k among the gutturals, t and d among the linguals, and p and b among the labials. (3) When the articular region is thrown into vibratory or oscillatory movements then we have the sound of the letter r which may be either guttural or lingual: and (4) the consonantal sound may be nasal in its character as the air expired is passed into the nasal passages. The result is that we get the lingual sound n, the guttural sound ng, and the labial sound m. According to Gretzner the consonants are divided into three classes: (1) the liquids or semi-vowels, which are either vowels or consonants, as for example, m, n, l, r, ng. If the sound is consonantal vocalization takes place in syllabic form. For example, p represents the abbreviation of a labial vocalization. He calls n, m and ng resonants because these are vowel in their nature at the end of words being produced by vibratory action of the vocal cords. In their consonantal use they really belong to the second class. Very little difference is found between the vocalization of l and n, the only difference being that the air is expired through the mouth on the two lateral sides of the tongue. Its vowel character is brought out in connection with other vowels as in the word "play." The letter r represents a vibrate and may be produced in different ways, as by lip, trilling of the tongue against the hard palate, by the vibration of the posterior part of the tongue against the soft palate and by the strong vibration of the vocal cords. (2) The explosives are produced in connection with an obstruction to the passage of air from the mouth. He subdivides this group into labials p and v: lingno-palatials t and d, and gutturals k and g. (3) Frictionals or aspirates represent all noises which are produced by the expiration of air in connection with a constriction of the oral tube in connection with which there is found vibrations. There is no obstruction to the vocalization and hence they are said to be continuous sounds. He subdivides these into the labiodentals f, v and w: the linguals s, sh, ch, th, z and j. H is a sound that is produced by the vibration of the vocal cords when they are separated, and it may be produced in any part of the vocal apparatus.

In regard to the nervous arrangement of the vocal mechanism we find that fibres from the superior laryngeal division of the vagus give off branches to the mucous membrane of the larynx, acting as afferant fibres in connection with which impulses pass to the central nervous system. In the superior laryngeal we also find the motor fibres for the crico-thyroid muscle which represents the principal tensor muscle of the vocal cord, all the other muscles of the larynx being supplied by the recurrent laryngeal nerves. These motor nerves both the superior and recurrent laryngeal, although they pass along the vagus truck, really belong to the spinal acessory or to its branch which is called the bulbar accessory. In connection with the nervous mechanism a distinction must be drawn between the larynx in its respiratory function and as an organ of vocalization. In respiration the glottis is open, and when the breathing becomes labored the glottis is enlarged in inspiration and contracted in expiration. The glottis seems to be in a condition of tonicity depending upon the tonic action of the posterior crico-arytenoid. The tonicity is dilatory in its action, the center being found in the medulla, possibly in connection with the respiratory center. There is a rhythmic enlargement and contraction during labored breathing depending upon the action of the medullary centers in connection with the sphincter muscles. These ryhthmic changes depend upon the action of the recurrent laryngeal nerves: for if both of the nerves are divided the glottis is contracted. On account of the contraction there is a dyspnoeic condition and the ryhthmic enlargement and contraction are destroyed, the glottis being immovable and resulting in the loss of voice. If the nerve is divided only on one side the glottis loses its normal shape, and in attempted vocalization the vocal cord on the divided side does not approximate to the vocal cord on the other side, with the result that vocalization does not take place. If the peripheral parts of both divided nerves are stimulated the vocal cords are approximated and the glottis is constricted. In the use of the larynx for vocalization the recurrent laryngeal nerves are utilized in the approximation of the vocal cords. When this approximation has taken place the larynx is capable of vocalizing low notes. When the vocal cords are resting they are sufficiently tight to allow of vibrations provided they are approximated. The cord tension must be increased, however, in order to aid production of high notes, and this is accomplished by the action of the superior laryngeal nerves in connection with the crico-thyroid muscles. If these nerves are divided, the vocalization of high notes is impossible. In vocalization, if a change is made from a high to a low note, the antagonistic action of the thyro-arytenoid muscles is utilized, and also the action of the recurrent laryngeal nerves. Vocalization is a voluntary action and generally depends upon characteristic volition. For this reason there is an area of phonation in the motor part of the cortex cerebri. In the monkey it is found at the lowest part of the ascending frontal convolution, lying between the Sylvian fissure and the lower extremity of the prae. central fissure. In the human subject the speech area is localized at the posterior part of the third frontal convolution, particularly in the left hemisphere. The artificial stimulation of the phonation area leads to the approximation of the vocal cords and the closing of the glottis. The pathway from this cortical area to the muscles of vocalization pass along the pyramidal tract, passing through the internal capsule; in connection with the medulla there seems to be a subordinate mechanism associated with the descent of the pyramidal fibres before they pass out along the laryngeal nerves. It is claimed that there is a local area for approximation and separation of the vocal cords found close together in the medulla. It is found that the paralysis of the motor fibres from the vagus that

supply the larynx, resulting either from injury or from pressure arising from tumor, produces a loss of voice. Paralysis may be found in the left recurrent laryngeal in the case of aneurism of the aortic arch. Paralysis may also be found associated with rheumatism or hysteric conditions. If vocalization is paralyzed in connection with one of the vocal cords the voice becomes falsetto and may in some cases result in the entire loss of phonation. If there is an incomplete unilateral paralysis of the recurrent laryngeal nerve we sometimes find a double tone associated with the double tension of the two vocal cords. According to some this double tone is found in cases where the two vocal cords touch each other as in the case of tumors, the glottis being really divided into two parts of unequal size, each part producing its own sound. If there is mucous in connection with the vocal cords or a swollen, inflamed or relaxed condition of the cord, hoarseness results. When the vocal cords are adducted and suddenly made to touch each other the voice becomes broken. If the soft palate is paralyzed there is a nasal sounding of the vowel, imperfect resonance and difficulty in vocalizing the explosive letters. In stammering we find an interference with sound formation. Stammering is produced by spasmodic contraction in connection with the diaphragm if it is prolonged. The expiration of air is absolutely necessary for vocalization, and as the spasmodic action of the diaphragm interferes with expiration, distinct vocalization is impossible. It may also be due to psychic or emotional conditions, but in these cases there is involved some psychic experience with respiratory action, so that in order to prevent stammering all that is necessary is to correct the respiratory action.

SECTION VIII.—Locomotion and Animal Mechanics.

The form and posture of the individual depends largely upon the skeleton structure and the bone union in connection with the different parts of the skeleton. The human skeleton is a firm and moveable framework, consisting of about 200 bones so united together as to form a single apparatus in its connection with the muscles, ligaments, tendons, etc. The human skeleton is of use in determining the posture of the body and locomotive movements. By the union of the bone with muscles and ligaments there is formed such a framework as renders locomotion possible. Articulation takes place (1) by means of bony structures, as in the bones of the skull. In the embryonic stage these bones are separated, but they gradually become to be welded together, only a fissure remaining to indicate the former separation; (2) by means of cartilages. The vertebrae and pelvic bones are united by fibro-cartilages, so strong as to permit of slight movement only under the force of great pressure, and restoring the bones to their original position after the removal of the pressure; (3 by means of bands of fibres. The carpus and the tarsus are bound together by ligamentous tissues, these ligaments not only connecting but also giving freedom for slight movements; (4) by means of joints. The surfaces of the majority of the bones are so arranged as to permit free action, the entering bones of the joint being covered with smooth cartilage and the jointed portion being supplied with a lubricating synovial fluid. There is a close junction of the cartilages at the edges of the joint cavities, so that not only is there free action in the case of motion, but also a strong connection preventing rupture. The bones are more strongly united by means of ligaments, these ligaments being used to strengthen the joints so that they can be relaxed or tightened according to the movements of the bones. Posture represents the equilibrium of the body, the body being

capable of being kept in one position for a length of time; for example, standing, walking, lying. In order to maintain equilibrium it is necessary that the center of gravity lie inside the basis of support. In the adult, for example, the center of gravity of the body is about 110 milimeters above the middle distance, in connection with the lumbo-sacral articulation, one and one-half mm. anterior to the sacral promontory. In the vertical position the basis of support lies between the feet, varying according to the separation of the feet from one another. In the erect position the feet are separated, the knees are extended, the legs are slightly extended outward, the pelvis extended backwards, and the arms extended downward. The body weight thus rests on the feet which normally rest on the ground at the heel, little and great toes. When the basis of support is in a single foot the equilibrium is diminished so that if the gravity line is only slightly changed their is danger of falling. In the vertical upright position gravity is secured anatomically so as to promote stability. The head is equilibrated on the atlas, and the muscles of the back aid in securing the spinal erectness. The center of gravity of the body trunk is posterior to the rotatory axis of the femurs, the body being kept straight by the action of the ilio-femoral ligaments and the dense fibrous aponeurosis surrounding the thigh. The entire body trunk is kept firm upward from the tibiao-tarsal articulation. If there is movement, even very slight, at this articulation a tendency is developed to move the upper parts of the body. Even in the steady, erect gait of the body there are slight tendencies to oscillation. In order to secure the steadiness of the body there arise a number of slight muscular movements, at one time anterior and at another time posterior, so that body steadiness is maintained. It is in connection with these movements that the muscular sense is developed so that normal sensations arise that lead to the oscillations of the body to preserve equilibrium. Vierordt has proved that when the sensibility of the soles of the feet becomes greatest, then the erect position is more firm.

The junction of the bones constitutes the basis of the rigidity of the trunk. The forms of joint vary considerably, but they have been classified as gliding, hinge, saddle, condyloid, ball and socket, and pivot joints. The joint surfaces are brought into contact in connection with the ligament; the capsule and the muscle tension. There is a tension associated with the elastic muscles, and in addition to this muscle tonicity aids in the preservation of this tension. The joint is fitted by a capsule so that the entire space not filled by the bone cartilage or other tissue is filled by the synovial fluid, so that the joint is free from air, the pressure of the atmosphere preserving the parts in close contact with one another. So great is the pressure that if all the softer parts around the joint are removed the pressure will keep the hip joint in its proper position. The bone movements take place largely in connection with muscle contractions, while the movement of the limbs and the direction of these movements is determined largely by the surfaces of the joints and the limitations that are found in connection with the ligament attachments. In these ball and socket joints there is the greatest variety of movement, as is the case in the shoulder and hip, movements being possible in all directions. The ball represents part of a sphere fitted into a capsule so that the motion of the ball takes place in connection with the depression. The saddle joint has a double axis of rotation as in the case of the trapezius in connection with the first metacarpal bone. In such a joint there is a possible movement in two directions, laterally and from the anterior to the posterior. A hinge joint can move only in one plane, the convex surface of one bone fitting into the cancave surface of another bone as in the case of the

humerus and the ulna at the elbow. In the knee joint we find another form of the hinge joint. The joint that is found in connection with the lower tibial extremity and the astragalus does not represent a simple hinge joint, so that there may be movement not only in connection with the transverse axis, but the joint surfaces may also move in the direction of the axis. It may be called a screw joint. In the sliding joints the articular surfaces are almost flat, the sliding taking place in various directions, although the movement is limited by the ligaments and the capsule. A pivot joint is found in connection with the atlas and the axis. A similar kind of joint modified is found in connection with the articulation of the radius and ulna by means of which phonation and supination take place. In some cases the bones are rigidly united together as in the case of the skull; in other cases bones are bound by cartilage as in the synchondroses in connection with the saccum and iliac bones. Very little movement is found in connection with this kind of bone, but it is of value on account of its elasticity and the stronger resistance it offers to separation. In connection with the joints between the vertebrae, although the movement is small in the case of the individual vertebrae, there is considerable movement of the vertebral column. In normal joint action there is a diminution of friction between the extremities of the bones in connection with the cartilages. During rest and movement all joint surfaces are in contact, being held in position by means of ligaments or bands of connective tissue. The close apposition of the joints is preserved by air pressure, and between the cartilage surfaces there is a synovial fluid secreted by the synovial membrane which acts as a lubricating substance. In the case of the hip joint there is a pressure of air equal to the weight of the skin, bone, muscles associated with the joint, so that even although these are all separated, the head of the femur will still retain its position. If the air is admitted by means of an artificial opening, the joint surfaces will separate, whereas if the air is extracted by a pump they will be again joined together. Thus the air pressure with the muscular tone keeps the joint in close approximation. The ligaments are designed either to strengthen and protect the ends of the bones or to prevent movements in an irregular direction. For example, in the ilio-femoral ligaments there is protection on account of the movement of the leg too far outward, so that excessive rotation outward is impossible. In the case of the knee joint we do not find a simple hinge joint, but there are two lateral ligaments, the internal and the external, and the semi-lunar cartilages between the bone. By extending the leg the external ligament is stretched, the internal ligament broadened so that in this extended position the knee cannot be rotated outward. By bending the knee these ligaments become flaccid, rendering possible a downward and upward movement. The forward stretching takes place in connection with the movement inward of the great toe, the external condyles of the tibia forming a semi-circle around the internal condyles, the ligaments checking the movement so that the femur condyles glide smoothly upon the tibia condyles, without separation from one another. Too much extension is prevented by the anterior crucial ligament, and too much bending by the posterior crucial. By means of the cartilages the pressure that is found in connection with the body trunk is distributed over a larger surface, so that there is a rolling movement of the articular surfaces both laterally and from the anterior to the posterior. The action of the muscles is not direct upon the bones, but takes place through the tendons. In the case of a narrow tendon the drawing firmer of a broader muscle is fixed upon one point of the bone to be moved so that motion takes place freely.

The muscles are adapted to the bones in various ways. The three forms of physical levers are found in connection with the bones, the bone moving representing a lever, the articulations in connection with a fixed bone being the fulcrum, the point of insertion of the muscle contracting representing the power, and the resistance being determined by a hindrance offered to the movements of the bone. (1) In the first class of levers the fulcrum is between the power and the resistance. In the extension of the forearm the elbow joint is the fulcrum, the triceps insertion is the power, and the resistance is found in the forearm weight in front of the articulation. In the case of the head balanced upon the vertebral column the articulation between the atlas and the occipital bone represents the fulcrum; the power is at the insertion of the neck muscle, and the resistance is the head weight in front of the articulation. The vertebral column in connection with the balancing of the trunk on the pelvis and the balancing of the leg upon the foot furnish examples of this same class of levers, utilized in connection with the stability of the body and also the body movements. (2) In the second class of levers the resistance is between the fulcrum and the power. In this case the power arm is longer and hence its small force may overcome a very great resistance. It is not common in the body. If the body weight is being lifted from the ground by the hands, where the hands rest on the floor would represent the fulcrum, the resistance would be at the elbow joint, and the power would represent the triceps force. In elevating the body on the tiptoes, the fulcrum is where the toes touch the ground, the resistance is the body weight that is transmitted to the astragalus through the tibia, and the power would be represented by the junction of the tendo-achilles and the oscalcis. (3) In the third kind of lever the power is between the fulcrum and the resistance. Here the arm of resistance is longer than the arm of power, and it is of value chiefly in connection with rapidity, being sometimes called the lever of rapidity. This is the common lever found in connection with human body movements. In bending the forearm upon the arm the articulations of the elbow represent the fulcrum, the flexor insertion the power and the weight of the forearm the resistance. The application of the power is usually made near to the fulcrum, and hence the arm of power is usually short as compared with the resistance arm. In this way the movements are rapid, and the seemingly clumsy appearance of the limbs is rendered unnecessary. The power is most advantageous when it is at right angles to the direction of the lever, as in the case of the arrangement found in connection with the masticatory muscles, the muscles of the calf of the leg and the head flexor muscles. In other cases the power is pulling in connection with the muscles in a slanting direction, and the power can be estimated by the parallelogram of forces, the one side corresponding with the bone and the other corresponding with the perpendicular line drawn from the point of attachment in connection with the muscle. The extent of the force depends upon the muscle attachment, and hence it is less as the angle becomes more acute between the muscle tendon and the bone. In the case of the extension of the arm the flexor muscles are acting disadvantageously on account of the fact that much force is spent in the drawing of the radius and ulna in opposition to the humerus so that this force cannot be utilized in movement. On account of the fact that the elbow is bent the force exerted comes to be directed more at right angles to the forearm bones with the result that there is an increased leverage. This leverage increases in connection with the muscles, is associated with the lessening of the slanting in connection with the enlargement of the heads of the bones and by the projection of the bone pro-

cesses as well as the sessamoid bones in connection with the tendons. When a muscle contracts its points of attachment approximate, with the result that the direction of the movement is regulated by the direction of the force in the muscle brought to bear upon the bones. In some joints the joint surfaces as well as the ligament attachments modify these movements, but if this is not the case the movement depends upon the action of a number of muscles and not of a single muscle. In some cases we find the muscle attached to two bones; the bones being moveable, the effect of the muscle contraction depending upon which end of the muscle becomes fixed in connection with the contractions of the muscles. In some cases the muscles take in two joints between their attachment, and thus complicate the results. The delicate adaptation of co-ordinate muscle movement depends upon the fact that in addition to muscle contraction we find the opposition of muscles involved. By means of the inhibition of these muscles there is a careful adjustment of muscle tension enabling the muscles to perform very delicate movements. The elasticity of the muscles as well as its tonicity forms the basis of rapid action, and also prevents a strange condition. In some cases the muscle shape has an important bearing upon its action. In the muscle we find a large number of muscle fibres, each fibre representing a contractile force. As the muscle increases in length there is a greater number of these contractile mechanisms, with the effect that the contraction is increased, as in the case of the sartorius muscle, which is capable of a great many movements. Hence the powerful activity of the muscle depends upon its possessing a great number of muscle fibres. Simple movements such as these seldom take place in connection with the body movements; the movements of one bone in connection with another usually call for the action of a number of muscles which co-operate together in producing the movement. In the movement of the forearm, for example, from a downward to an upward position, many muscles are brought into play. In the movement of the lower jaw upward the temporal and masseter unite in double movement, for the bending of the forearm upon the arm the biceps and the brachialis anticus also unite in a double movement; similarly in the flexion of the foot we have the action of the gastrocnemius and the soleus.

In some cases the muscle is found in connection with a single joint as in the brachialis anticus, whereas in other cases it is found in connection with two, as in the biceps muscle. Often there is a loss of power on account of the slanting direction of the insertion of muscle tendons in the bones, when muscles act in antagonism with each other, and by the slanting of fibres in different directions even in the same muscle. The slanting attachment is sometimes lessened by the enlargement of the heads of the bones, the protuberances as well as by the existence of the sessamoid bones, and the pulleys in which the direction of the tendon is subjected to change and the presence of the pulley as mechanisms, in the case of the superior oblique muscle of the eyeball. The quadriceps extensor is rendered efficient by the action of the patella in order to prevent the bones of the leg from being pulled against the lower part of the femur. By means of the patella the tendon fibres are pulled forward and attachment is made obliquely to the tibia. In the attachment of muscle and bone of the human body there is a considerable loss of force, although this is in part made up for by increased motion. Even during rest the muscles are slightly extended so that they have an elastic action in connection with the bones. In this way power is saved because the muscles are in a constant tonic condition of contraction, and are fully prepared to act at the slightest stimulus to activity. If one

antagonistic set of muscles acts there is an effect on the opposite set, as in the case of the flexors and extensors of the arm. Thus the latent elasticity is called into play so as to keep up the normal movement of the limb. The muscle sheath has an important bearing upon its activity. The muscle consists of a great number of fibres representing a series of contractile forces. If the fibres are long as in the sartorius there is the action of a great number of mechanisms, so that there is greater power of extended movements. Muscular power is proportional to the cross-section area of the muscles and to the amplitude of its movements. The power of movement as well as its extent is usually in proportion to the length of the muscles, but this represents a small power compared with the larger power found in the thicker muscles with a greater number of fibres as in the case of the peroneus longus.

THE ERECT POSTURE.

There is very little muscle exertion necessary to maintain the erect posture. It is simply the balancing of the body, preserving the center of gravity over the basis of support. In this erect posture the centre of gravity of the head is anterior to the occipito-atlantal articulation, so that the head is free to move forward. The centre of gravity of the body including the head is in a line slightly posterior to a line drawn between the hip joint centers, giving the body a tendency to backward movement. The gravity line of the head trunk and the upper parts of the lower limbs is slightly posterior to the axis of the knee joints; the gravity line of the entire body is slightly anterior to the line joining the knee joints. It is this that makes the body tend to bend the ankle and the knee joint. In order to the erect position the muscles must be active, otherwise the dead body could stand upon its feet as well as the living body. If a person is required to stand upon the feet for a long time a fatigued feeling results. There are a number of standing attitudes. In the soldier posture the heels are together, the toes being turned outward, the legs straightened and in a parallel line, the pelvis being thrown back and the vertebral column straightened, with the straight, forward look in connection with the eyes. Very few muscles are necessary to maintain this posture, as the knee extension throws the gravity line a little anterior to the rotatory axis, extending the ligaments and stiffening the joints. The throwing backward of the pelvis throws the gravity line a little posterior to the hip joint, extending the ilio-femoral ligament. The ankle joint is strengthened by the tension of the muscles in the calves of the legs so that the body is prevented from falling forward. Muscular action also balances the head and strengthens as well as straightens the spine. While this posture is very stable it is not very comfortable, chiefly on account of the fixation of the muscles. Less fatigue is felt by allowing the muscles to flex somewhat, maintaining the body in balance by the muscles, particularly if the positions change frequently so as to change the action of the muscles. The best resting posture is to support the body weight upon one leg, the pelvis being thrown back in such a way as to rest the body weight upon the femur, the other limb being made use of to support and stay the weight of the body. It is impossible to preserve the body in an absolutely stable, erect position for a considerable time, because the body tends to move. Every individual has a characteristic swaying movement associated with the body. In order to maintain equilibrium afferent impulses must pass to the co-ordinating centers, so that efferent impulses may pass out to the muscles. If these impulses are suspended, as by the closing of the eyes, then the equilibrium of the body is interfered with. The same thing would be

true of the suspension of the sensory impulses from the feet, the joints, the muscles, etc., the effect of this swaying movement of the body being to remove the pressure from time to time, localizing it at different points so that the muscles might be continuously active in bearing up the strain of the body weight.

LOCOMOTION.

When there is a deviation from the erect posture, the body assumes various attitudes, such as walking, running, etc. Animal movements were carefully studied by means of observations, and more recently by means of measurements, and the use of delicate instruments, such as those invented by Marey; they have also been studied in connection with the instantaneous photographic methods. We are indebted to the investigations of Marey, and the instruments he has invented for most of our information on this subject. By the use of a shoe with a thick sole in which there is an air chamber communicating by means of a tube with a recording tambour, when the foot presses upon the ground there is a compression in the air chamber, and this is transferred to the tambour to be recorded on a cylinder borne in the hands. A tambour is also put on the head to record the vibrations and oscillations of the body, so that three tambours record the movement, one for the body and two for the feet. In the case of walking the body never leaves the ground, one or other of the feet touching the ground while the body is moved forward. Before the walking movement begins the body weight is thrown on one leg, the other leg falling back while the knee and ankle become flexed. Then the body is inclined slightly forward, after which the leg that is behind is extended and the body is thrown forward. As the center of gravity is moved forward from the leg that supports the body, the movement of the other leg provides a support for the body. As this body weight falls upon the leg moved forward the other leg is free, and then thrown back again. The forward movement of the body is caused by the inclination forward which tends to throw the body forward, and it is also due to the pushing action of the leg. Very little action is performed by the body in the act of walking, the swinging movement of the leg being pendular and largely passive. Muscular action is necessary or order to create these movements. Gradually the leg that supports the body leaves the ground, the large toe being the last to touch the ground, so that when it leaves the ground complete extension of the leg takes place, the inclined position being assumed instead of the vertical position by the horizontal movement of the pelvis. There is a slight flexure of the hip joint with the result that the extended limb is too short, becoming a swinging limb, this pendular movement taking place in connection with the action of the extensor muscles which come into play to lengthen the limb, with the result that the pendular leg becomes the supporting leg when the foot touches the ground. One leg assumes the position of pushing the body while the other is resting, the leg that is supporting the body being extended, the body being prevented from falling forward by the swinging movement of the other leg, which results in the forward movement of the center of gravity. By the transference of the body weight from one leg to another, there is produced a slight oscillation laterally, which produces a swaying motion sideways that is prevented from becoming excessive by the strengthening of the leg in the pendular movement, producing a slight up and down movement. This tendency to oscillate the gravity center laterally, is prevented from becoming excessive by the action of the arms, the oscillations upwards being prevented by the extension

of the moving leg assisting in the support of the pelvis, while the other limb is being moved forward. Movement forward of the leg is not a muscular action, but depends rather upon the swinging forward of the leg through the arc of a circle. When the body becomes exhausted then the muscles are called into action. Rapidity in walking is accomplished by the forward inclination of the body, and the increased flexure of the legs, so as to permit of a greater force pushing the body forward by the movement of the leg, the muscles assisting in the change of the gravity line. In rapid walking the leg that is advancing comes to the ground before the complete oscillation has taken place. The rapidity with which the limb advances depends upon its length or on the separation of its gravity center from the point of rotation. The rapidity of the swaying motion of the limbs is determined by the pendular swing in connection with gravity. The velocity is increased by depressing the center of gravity in connection with the body, the increase of the limb flexion, the increase in the force with which the advancing limb leaves the ground or strikes against it as well as by increasing the length of the steps and shortening the time during which the supporting limb rests upon the ground. Thus, while the body is being moved forward it is supported by the feet, one foot always being in contact with the ground. Before the movement of the body begins the body weight rests upon one leg, the other leg falling backward, the knee and ankle being bent. Then the body is slightly inclined forward, and the limb that is behind is extended to its full length, impelling the body forward. The work that is done by the limb in walking is very limited, because the swing of the limb is a passive action.

In the case of running there is a greater inclination of the body than in walking, the leg that is behind leaving the ground before the advancing leg reaches the ground. In this case there is a short period during which the body is not supported by the legs. Thus the body has a greater inclination, there being a greater flexure of the legs and greater vertical oscillation. The body is driven on by a succession of springing movements, at times both feet being removed from the ground, the one leaving the ground before the other reaches it, the rapidity of the running movement depending upon the forward inclination of the body and the strong action of the muscles, the vertical body oscillation being greater than in the case of walking.

ANIMAL MECHANICS.

One of the characteristics of life is motion, living beings having been compared in all ages to machines. In the animal we find a mechanism of levers, pulleys, valves, etc., the working of all this mechanism being called animal mechanics. These mechanisms are dependent upon the vital force for motivity, life setting these mechanisms in motion and keeping the motion continuous, as well as in adaptation to the mechanical life and the purpose of the mechanism. Motion is manifested in connection with functional life. Properly speaking, animal mechanics would cover the entire mechanism of motion in connection with the heart, the blood vessels, the lungs, the intestines, the glands, as well as the muscles and the bones—all of these movements being essentially associated with the organic life. A distinction has been made between movements that are involuntary and those which are voluntary; the former being said to be associated with the organic life, whereas the latter are associated with the relative life of muscular action and locomotion. This distinction, although claimed to be based on anatomy and physiological function, is really not so; it is claimed

that here we have the essential difference between the muscle force of the organic life in connection with smooth muscle under the nervous influence of the sympathetic system, as compared with the muscular force that depends upon the striped muscles, in obedience to the nervous action of the cerebro-spinal system. This distinction, as we have seen, cannot be carried out, because the heart is an organ which is associated with both the striped and the unstriped muscle, and hence is very closely related to the voluntary muscles. This question of voluntary or involuntary action does not enter into the discussion of animal mechanics, because in connection with the generation of motion it is necessary to have muscle fibre, blood vessels and nervous action to excite these fibres to activity. In this way we have the complexity of voluntary and involuntary elements associated with the action of the animal mechanism. All that was said in connection with muscle and nerve applies here in relation to the motor and locomotor mechanisms that are found in connection with the human body. We are not concerned in the discussion or definition of force; all that is necessary for our purpose is to know that when matter acts or passes through a change there is a phenomenon, the unknown cause which has produced this phenomenon being called force. Hence force cannot be separated from matter: it is indestructible, and although we speak of the forces of nature as being many, the forces of nature can be reduced to a unit, although the force may assume different forms. We have seen that muscle, when artificially stimulated, is capable of exhibiting certain phenomena of motion, these artificially produced motions giving us some insight into the normal movements that we find in connection with the human body. By the stimulation of a nerve we have also seen that an impulse may be originated and communicated through the nerve to a muscle or muscles, with the result that contraction takes place in the muscles on the basis of an exciting cause. In living animals the neuro-muscular relations are preserved intact, and the measure of these relations, as well as the work that is involved in these relations, is a matter involving considerable difficulty, although it forms the basis of mechanical work in connection with the animal life. A motor can work only on the condition that effort is involved, and that this is associated with motion. In the contraction of muscle no external work is done except during the contraction. When the contraction limit has been reached then there is no work performed, although considerable effort may be involved in sustaining the contraction. It is evident that the same forces are at work in the living animal mechanism as we find in the arbitrary field of dead muscle and nerve. In the lifeless machine we find certain organs which act as media between the forces that are used and the resistance overcome. In the same sense we find organs in the animal mechanism, so that the laws of mechanics are applicable to the living machine in the same sence as to the lifeless machine. In order to utilize a certain amount of force it is necessary to combine it in such a way that its effect may be concentrated. The amount of work represents the result of the resistance multiplied by the space through which it passes. These factors vary, and hence we find differences in the amount of work that is done. In connection with muscle, the larger a muscle is it is capable of a greater amount of work. At the same time the contraction of a muscle is in proportion to the length of the muscle. When a muscle is contracting it is shortened, and this shortening is influenced by the fact that it is in close relation, by origin and insertion, with bone or tendon. The amount of work that is done by a muscle is in proportion to the length and the transverse section of the muscle; in other words, to its volume. In this way it is possible to find out what force is possessed

by a muscle and to compare it with the force of other muscles as well as to find out the form which the work assumes that the muscles perform. In regard to the form assumed by the muscular work, it can be easily determined from the form of the muscle. In the case of a short and thick muscle there is a strong effect, whereas, if the muscle is long and thing, its action will extend over a longer range, while the energy will be more feeble. In the case of the sterno mastoid and the sartorius we find an extended range with a large extent of movement. In the large pectoral muscle we find a muscle that is capable of strong action with slight contraction.

In connection with the muscles as we find them in the human body there is a specific force associated with the muscle-tissue as we find it in different animals. Hence, according to Weber, frog muscle is capable of energy equal to 692 grams per square centimeter, while the human muscle is capable of 1,087. It is also stated that the frog works with a pressure that is below one atmosphere, while in the case of human muscle the pressure is greater than that of a single atmosphere. We cannot apply all of the mechanical principles that are found in connection with lifeless mechanisms to the living mechanism of the human body. This is rendered impossible on account of the variations found associated with nutrition, as well as the exercise of the will power. Hence the living menchanism is distinguished from the lifeless mechanism from the fact that the former is free. Muscle can act only when it is in connection with the living vessels and nerves of the organism. The same thing is true of the bones. The blood circulation is carried on on the hydraulic principle by means of a pump, valves and tubes; but there is a fundamental difference, the heart being a pump in which there is no piston, its variations depending upon the varying contractile conditions associated with the blood vessels. In the living human body it is possible, to a limited extent, to estimate the dynamic force, but this cannot be estimated so absolutely on account of the fact that fatigued or exhausted conditions are associated with the living animal, such as we do not find in connection with the lifeless machine.

In regard to form as applied to the different organs of the body and the nature of the functions that these organs discharge, we find the special adaptation of particular organs to particular functions. Hence we find that the transverse section of the muscle represents activity; in the athlete, for example, this being a sign of athletic force. In regard to the length of the muscles, we find that there is a measure in the length of the extent of the movement of which the muscle is capable. Here we have the distinction between the contractile fibre and the practically non-contractile fibre that is found in the tendon. When the muscle is shortened under contraction this shortening represents a constant factor which is represented at about one-third of the length of the muscle. In this way we are able to estimate the contractile force of the muscle. All the muscles which are capable of variation in connection with their attachments require to be long muscles, and these muscles are capable of a large extent of movement. On the other hand, muscles which produce a short movement require to be shorter. Thus the finger muscles represent short muscles, but their action is extended by connection with long tendons which bear to the finger phalanges movements which were at first only slight. In connection with the sartorius muscle we find a muscle so long that it cannot be displaced by any other muscle to such an extent in connection with its attachment points. The sterno mastoid and the great rectus abdominis also represent long muscles whose movements are capable of considerable extension. We must not forget the fact that

the attachment of the muscles may modify, to some extent, the extent of movement possible in connection with these muscles. Borelli has shown that the muscles whose fibres are obliquely inserted into tendons represent short muscles which seem to be long muscles. Facts like these require to be taken account of in order that we may appreciate the nature of the contractile parts in relation to the length of the muscle. In comparative anatomy we find great variations in the form and function of the different muscles. In animals like the kangaroo, the leaping muscles, like the glutei, the gastrochemci and the triceps, extensor cruris, are very fully developed. In the case of the birds, we find, for example, a considerable variation in the pectoral muscles in relation to wing movements. Even among the birds we find great variations in these muscles, as in the eagle, the wing strokes are of slight extent on account of the fact that great resistance is met by the wing, so large in size, as it passes through the air; whereas birds of small wings move them to a very large extent, this compensating for the diminished resistance that is met with in connection with the wing muscles. In the mammels the differences are not less marked, although these differences cannot be absolutely carried out. For example, we can easily identify the biceps femoris in all mammals, although great variations are found in its lower attachments. In some animals we find its insertion all along the leg, while in other animals which have the power of jumping there is a great elevation of the lower attachments of the biceps. In the human subject the biceps insertion is high up in the fibula. It has been pointed out that here we have an anatomical difference between the white and the black races, the insertion of the biceps in the white races being higher up than in the black races, the latter being more like the ape. In connection with the flexion and extension of the knee the bony structure describes a circle arc that is much larger as it recedes from the center representing motion. These points will also move from the femur, or the ischium, on the basis of the circular movement and the extent of it. Large movements correspond, as we have seen, with large contractile fibres. In the human subject the biceps is inserted at the lower and very near the knee, so that the extent of the movement is slight, and there will be only a short length of contractile fibre. In the lower animals, like the ape, the insertion takes place lower down, giving larger motivity and a greater length of muscle with a smaller tendinous attachment. In the rectus internus muscle of the thigh we find the same variation in attachment. In the human subject its attachment is very close to the knee and its tendon is very long, so that the muscle fibre is short and the extent of movement is also short. In the semi-tendinous muscle the inferior attachments are very close to the articulation of the knee, whereas in lower animals we find a lower attachment with hardly any tendinous attachment. Thus we find the form of the muscle determining the character of the function discharged by the muscle, where there is transverse development being found strength, and where there is increase in the length of the muscle there being a corresponding increase in the extent of movements. The question arises, does this adaptation take place in connection with the performance of different functions by different animals, just as we find an increase in muscle volume corresponding with the use that is made of the muscles? Does the fact that an animal performs more extended movements give to the muscle an increase of length? These questions have been discussed and solution has been attempted on different theories. Among the most prominent we find the theory of development in opposition to the older theories. Without entering into the discussion of these theories we might say that the older theory took the position that the world of animate nature is repre-

sented by certain almost unchangeable types of life which have scarcely, if at all, the power of alteration from the primitive type. These slight changes depend upon climate, nutrition, or the principle of domesticity. As opposed to this older school we find the more modern theory that the animal life is constantly being modified by its environment, these environments producing new aptitudes that modify the organism, with the result that variations are found on the basis of development. According to Lamarck there is an external variation, but according to Darwin there are also internal influences which modify the animal life, the fundamental principle of which is natural selection. In some cases certain individuals receive a greater chance in connection with the struggle for existence, the increase of physical vitality giving to them an added force, so that they are able the better to survive those changes that take place around about them. In connection with both of these theories it is claimed that there are objections.

Darwin, however, has fully discussed his theory of natural selection and made it so plain, that it is undoubted the principle of selection does modify the type of animal life. The newer theories take account of both the internal and external variations. It is impossible to state with certainty what is the cause or the causes that have produced modifications in the functional development, but we have the general statement of Guerin that "function makes the organ," expressing generally the modifying action of function. This is not less true of the muscles than it is in connection with the other parts of the body. For example, the bones, the articulations and the muscles are considerably modified by variations in function; the alimentary apparatus, under the influence of the changes in alimentation, modifies its functional activity, and even the senses become entirely changed, either by acquiring or losing certain powers. Thus we find changes of function from the physiological standpoint resulting in modifications of the structural or anatomical apparatus. When we have admitted this point we have really shown that the skeleton and the muscular apparatus have been harmonized with the movements of the animal life, as these take place in connection with its individual conditions. The skeleton has been considered the invariable part of the human organism because it is regarded as the framework of the body, whereas the softer parts of the body tissue, whether lying in the cavities or upon the surfaces of bone, have been modified under the influence of the bony structure. A close examination, however, indicates the presence of a very large number of minute hollows which have undoubtedly been associated with the origin of muscles. In other parts of the bony structure there are found grooves which have been associated with tendinous structures. In this way it is found that there are muscles and tendons which may have possibly disappeared on account of their loss of function, the stronger and truly functionalized muscles having taken the place of the weaker ones in the struggle for existence. From this standpoint the shoulder bone, at its lower extremity, is marked by a small spherical projection; it also indicates that there were two kinds of movements, and quite close to this we find the surface in which there is an indentation representing a groove, associated in some way with the fore-arm function and extension. In the skull we find various cavities which cannot be explained on any other supposition. The nerve paths through the bones are represented by foramina or furrows which form canals along which the nerves pass as they make their way to the distant parts of the body. It is claimed by some that bone is too hard to be capable of such indentation as would be necessary in order that the softer parts of the body might furrow out these cavities. Hence it has

been concluded that the skeleton represents the invariable part of the organism. In support of this theory it is claimed that the variations which are found, for example, between the humerus and the femur, instead of depending upon muscular effort is an essential part of the organism. In modern times it has been pointed out that the bony system is capable of considerable variation, such variation taking place during the individual life. It is found that by pressure, even upon the hardest bone, there is produced a cavity or alteration in the structural form, so that it is completely subject to the influence of the softer parts. For example, in the case of an aneurism of the aorta when it comes in contact with the sternum, or with the clavicle, it absorbs a part of the bone, passing through the bone in a comparatively short time, offering less resistance to this tumorous action than the softer parts of the body. The same pressure is found in connection with the blood; and as the blood is found at every part where an artery is in contact with the bone, there is the same absorption of bony substance, with the result that the artery indents for itself a groove in which it finds lodgment. This is illustrated in connection with the internal surface of the parietal bones in the human skull. The same fact is evident in connection with the varicose veins; for example, in connection with the anterior part of the tibia in which the bone is furrowed out by the distended veins. These are examples of the action of the softer tissues of the body upon the bony structures. The same action is found in connection with the muscles as in connection with the fibula, which assumes its characteristic form under the influence of the muscle action. The action of the tendons also hollows out the bone in the development of the human skeleton. It is quite true that the articulated surfaces are provided with cartilage, which is lubricated by a synovial fluid, thus assisting the movement. The bones in this case are surrounded by ligaments which keep the muscles in their proper place. In the case of dislocations it is often found that articulated cavities are entirely altered and a new articulation may be formed with cartilage, synovial fluid and ligaments. In this case, certainly, function has produced an alteration.

It is more difficult to account for the apophyses which are found on the surfaces of the skeleton, representing the bony protuberances to which muscle attachment is formed. This can be partly accounted for by the influence exerted in the formation of indentations and also by the action of force which is associated with all the different parts of the skeleton where muscle attachment is found. The traction that is found in connection with the muscle is proportional to the muscle force. In line with this we find these protuberances in connection with the tendinous attachments of the stronger muscles, indicating that the protuberance is connected in some way with the action that takes place in connection with the muscle. In line with this it is found that on the left arm these protuberances upon the bony structure are less marked than on the right arm, because in ordinary circumstances and individuals the left arm is used less frequently. In the case of the paralysis of one extremity the action of the muscle is suspended, with the result that if the paralysis begins early in life the bone continues to exhibit its embryonic characteristic, not having been modified by functional action. This conclusion has been confirmed by comparative anatomy, which seems to indicate that the enlargement of the apophyses involves the increase of energy in connection with the muscle. It has been pointed out that the humerus is considerably modified in certain animals; for example, in those animals that live by burrowing in the ground, the humerus becomes almost unrecognizable, on account of the great increase in the number of protuberances

representing muscle insertion. It has been shown also that in aged people there are longer apophyses in connection with the vertebrae, and also greater angularity in the curvatures of the ribs. It is almost impossible to point out the variations that are found in connection with the different parts of the skeleton in different animals, these differences being the basis of considerable modification in the bones. In pathological conditions of the human system we also find the development of artificial apophyses, representing the abnormal outgrowth of bone. In some diseases the skeleton is covered over at a great number of points with these osseous protuberances, all of these being developed in connection with muscular attachment. Bone curvature is another example of this same phenomenon. It has been shown that the humerus represents a contorted femur in the mammals, the axis having turned upon itself. It has been found that this contortion increases from foetal life; during childhood to maturity the contortion being increased with the development of muscular activity. In connection with articular surfaces we also find the modifying effect of function. The friction that is associated with these articulations has produced curvature and also made the surfaces smooth. Where the surface has a great number of different degrees of curvature we find very extended movements, while movements that are not so extensive will produce a curvature corresponding with the smaller arc, with the result that the radius of curvature is short if the movements are extended and long if the movements are less extended. In the tibiotarsal articulation of the human subject we find a small radius of curvature, on account of the fact that the foot has extended movements upon the leg. In connection with the tarsus there is an increase of the radius curvature, as the bones become less movable. In the scaphoid the articular surfaces represent a large radius, the radius increasing as we pass into the metatarsal articulation on account of limitation of the movement; there is a diminution of the radius in connection with the metatarsal articulation with the phalanges and the phalangeal articulation. When articular movement takes place in a single direction there is a curvature of the surfaces only in that direction, as in the case of the articulation of the elbow and the condyles of the jaw. If the movement takes place in two directions at the same time there is a double curvature, the radii of curvature being either equal or unequal, depending upon the extent of the movement. In connection with the wrist we find flexion and extension movements that are extended, while the lateral movements are limited, with the result that in the case of the elliptical head of the carpus we find a curvature of small radius in connection with flexion and extension movements and a larger radius in the lateral movements. This same idea has been carried out in connection with articulations that are found in different kinds of animals, as in the case of birds and flying animals, compared with apes and the human subject. The conclusion is that the bony structure of the body is subject to modifications, especially in connection with muscular functions. All the protuberances and indentations of the skeleton are associated with some external force whose action upon the bony structure has modified it in some way. Thus function has modified, to a very considerable extent, the skeleton. The same principle is applicable in connection with the muscular system. Bony resemblances indicate the presence of or attachment to muscles that resemble each other. On the other hand, a bony structure of a peculiar form indicates some peculiarity in connection with the muscles that are attached to this bony structure. What has been said seems to indicate that the bony structure is modified by the muscle. The question arises, does the same or a similar modification take place in connection with the muscles?

The claim is made that the muscular system is subjected to modification in connection with the nervous mechanism. Hence modification takes place in the muscles on the basis of the nervous action that is under the control of the will, the muscles being modified, both in form and in volume, so as to accommodate them to the most skillful performance of the actions determined by the will. All of the actions of the animal life are to a certain extent influenced, if not governed, by the will, because there is nothing in the organic structure, whether of bone or of muscle, that is entirely subject to the play of chance. The great variation in the muscular apparatus is found not only in different animals, but also in different muscles of the same animal. Hence we find variations in the length and volume of muscles, unequal distribution of the contractile fibres and the tendon fibres, these being based upon muscular function. In anatomy we can distinguish the form of the organs, to a certain extent, in the basis of function. Experiments in connection with the change of function indicate the way in which modifications may take place in the muscles when subjected to new conditions. These experiments are, to a certain exetnt, confirmed by pathological and surgical data. It has been found that active movement on the part of a muscle is at the basis of the continued existence of the muscle; for if the muscle remains at rest for a considerable time there is a decrease in volume as well as a change in the muscle element. The striped muscle fibre gives place to fatty corpuscle cells, these increasing in numbers until the muscle substance is entirely changed. This represents fatty degeneration, and may be followed by the disappearance of these corpuscles on account of absorption. In this way there is a change of volume based upon functional or non-functional activity, and this change is carried to such an extent as to involve the entire disappearance when the function is destroyed. This is found to a greater or less extent in paralytic cases in which the nerve action is destroyed, also in cases of dislocation on account of which the insertions of the muscle are brought close together, producing inactivity of the muscle. The same thing is found in cases of fracture and also in cases of anchylosis, in which there is developed an abnormal relation of muscles that interferes with the normal muscle contraction. On the other hand, if the muscle is changed in the extent of its movements, the question arises, what modifications will this produce? In some cases of imperfect dislocation or anchylosis there is an interference with the extent of the movements resulting in modification of the functional activity. Some discussion has taken place in regard to the changes that are involved in what is called club-foot. In some cases there is a twisting of the foot, on account of which the surface that should be next the leg becomes next to the ground; in other cases there is an extension of the foot, with the result that walking takes place on the extremity of the foot. In these cases the limb muscles become degenerated, or at least changed, on account of the limited motion of their action; whereas those muscles which do not act at all degenerate and disappear. In the case of those muscles which are partially active there is a modification in the muscle substance, the contractile substance being diminished and there being a substitution for it of tendinous tissue. In regard to these muscular changes it is found that the muscles assume one of two forms, either that of fatty degeneration or the form of fibrous tissue. In the case of the gastrocnemei muscles the attachments and the functions are different. The insertion of the two muscles is found in the Calcanean in connection with the achilles tendon, so that the muscles represent extensors. The upper insertions are different, however, the soleus being inserted in the bones of the leg having as its function that of extension of the foot. The two gas-

trocnemei are inserted in the femur above the condyles, and have in addition the function of flexing the leg on the thigh. In the case of foot anchylosis the function of the soleus is destroyed, with the result that it degenerates, while the gastrocnemei do not degenerate, still preserving the function of flexing the leg on the thigh, changing their movements from double to single. The result is that the gastrocnemei muscles are modified to this extent, that their fibres are shortened and they become partially fibrous. In the examination of the muscle at different stages of life there are found to be considerable variations, so that it is claimed the muscles have characteristic properties associated with particular stages of development. In the earliest stages they are found to consist of contractile fibres, as they advance in age the fibres becoming less contractile, while there are substituted for the ordinary red fibres the white tendinous fibres. In the case of the diaphragm, in childhood it is found to be largely muscular, but as in old age it becomes fibrinous, the diaphragm tendon being extended into the muscle fibre representing aponenroses. In the child the leg muscles are found to consist mainly, if not altogether, of contractile muscle substance, while in old age it is substituted by the tendon which takes its place, while the muscle becomes reduced in size and in length and is found associated with the upper part of the limb. In connection with the muscles of the back we find the same tendency in old age to substitute tendon for muscle fibre. There must be change taking place in the muscle as the individual advances in life, especially if muscular function is limited. The articulations of the vertebral column as well as of the limbs become anchylosed, diminishing the capacity for flexion both of the limbs and of the trunk. This represents the reason why so extended movements are possible on the part of the child, and a growing individual as compared with the aged person. In old age there is a loss of flexion, and this loss of flexion limits the extent both of flexion and extension on the part of the muscle. Hence we may conclude that the muscle functions change with the different changes of life, becoming more limited as the contractile muscle fibre becomes more limited. As we have seen already, there is a perfect harmony existing between the function of the muscles and the form of the muscles. From this it may be concluded that the muscle, as well as the organ which is formed by the muscle, is subjected to modification by the change in function. This is not a new principle, because training in the case of a race horse as well as of an athlete depending upon special exercise, is designed to modify certain function. This modification of function involves at the same time a modification in the anatomical character of the muscle.

Hence in the human subject we find that man has modified his muscular as well as his skeletal system to the aptitudes and functions that are associated with his daily life. This represents an important physiological principle, that the muscular function modifies the structural form, whereas nervous activity also modifies the muscular form. These modifications depend upon conditions associated with food, habits of life, changes in climate, atmospheric conditions, etc. The most characteristic manifestation of movement is that of locomotion, aside from the motions or movements of the body and of the different parts of the body. Locomotion represents that action in virtue of which a living being, adjusting itself to its environment, moves about. Locomotion, therefore, may be considered as including certain definite types, according as the locomotion takes place on the surface of the ground or in the media of water or air. Attemps have been made to identify the different locomotive types in all these different forms of locomotion, but without success. In all forms of locomotion

there is a force expended, this force resulting in a certain amount of displacement. A classification has been adopted in regard to these forms of locomotion on the basis of resistance. Three forms of locomotion are spoken of, namely: terrestrial, aquatic and aerial. It is impossible to attempt a minute classification of these movements. Terrestrial locomotion is said to consist of two principal forms: in the one form we find the attempt to press upon the ground in a direction opposite to the movement that is intended, such as we find in walking, running and leaping. The limbs in this case represent levers which are subject to changes in length, being shortened by the bending of the articulations and being lengthened by being drawn up. When the leg is flexed, if it touches the ground at the extremity and at the same time an attempt is made to extend the limb, this is only possible by moving the surface on which the foot rests away from the extremity of the leg. The ground is resistant, so that the body yields to displacement. This displacement involves either a variation in length or a variation in the angle between the limb and the animal body. In the second form of locomotion we find creeping, in which there is an effort to drag the body, the animal laying hold of some part of a surface and dragging the body after it. In the different kinds of locomotion there is great variation in the amount of resistance that is necessary to be overcome, this resistance depending upon the medium in which the locomotion takes places, whether aereal, aquatic or on the surface of the ground.

From the standpoint of the physiology of muscle we found that in attempting to estimate the work of a muscle we fix it strongly by one of its attachments and find out the extent of its movements. In this way by knowing the weight which the muscle lifts when it contracts and the length of space through which the weight is lifted we are able to estimate the amount of work that is done. These, however, represent conditions that we cannot estimate, except ideally. When a person is walking one foot is placed on the ground and the other foot is flexed while resting on the ground, giving to the body a forward or upward movement. If the ground is perfectly solid the movement will take place in the direction of the body trunk, whereas if the body yields only a part of the force it will be converted into movement upward. In the case in which the ground is perfectly solid none of the muscular work is lost, whereas if the surface of the ground yields there will be a displacement of the surface. According to Newton this law is laid down: "that the action and reaction are equal." This does not mean that one-half of the work is expended on the ground and one-half upon the movement of the body. The application of this law is found possible in the case of walking as we find this act of locomotion in man. From the time of Borelli to recent times considerable advances have been made in connection with the analysis of locomotive conditions. Human locomotion is very difficult of analysis, on account of the fact that observation cannot be accepted as a perfect test; neither can the graphic method be regarded as giving us a perfect analysis. In the case of walking, as we have seen, the body never leaves the ground. In walking the body weight is alternately passed from one limb to another, so that as each limb places itself before the other there is a continuous carrying forward of the body. This movement, although it seems to be simple, is very complex, on account of the fact that every movement of the limb involves the change of support, the variation in the flexion and extension of the articulation. There is also the variation in the pressure of the feet upon the ground that can be determined only by the rapidity of the walking. In addition to this there are oscillations of the body, the result of the touching of the ground by

the extremities of the limb and the movements of the different parts of the body. Thus the oscillations are different in their nature, some being vertical, some horizontal, and some complex. There is also an inclination of the body that takes place at every movement, the body revolving around the coxo-femoral articulation, while it is being slightly flexed in connection with the vertebral axis. There is also an oscillation of the pelvis in connection with the lumbar muscle, while the anterior extremities are utilized in balancing the body and diminishing the opposing influences that tend to destroy the equipoise. The motive force in walking is associated with the action of the exterior muscle of the thigh, the leg and the foot. In the lower limb we find a column of bone and muscle, varying in its angles and at times becoming perpendicular in connection with pressure both from above and below. The pressure that takes place upon the ground is equal to that above in the body, thus assisting in the forward movement of the body. Registering arrangements have been invented for the purpose of determining the duration as well as the variations and the intensity of this pressure. In connection with the tracings that are found by the use of this apparatus, the impact of each foot upon the ground gives us a curve, the pressure of the one foot beginning at the time when the pressure of the other begins to diminish, the period representing the length of time during which each foot is supported being represented by a horizontal line uniting the minima of successive curves. There is the same duration in the case of the impact of the right and left feet, so that the body weight rests for the same length of time upon each foot. Where the impact of the two feet is different we have the condition of lameness. During a short time the body is supported by one foot, this period of time being varied according to the rate at which the individual walks. There is a period that lies almost intermediate between the impacts of the two feet when the body is partly supported by one foot and begins to rest upon the other foot. The degree of pressure which the foot exerts upon the ground has also been traced out in connection with the curves that are associated with the walking movements. In walking it is found that the pressure of the feet upon the ground is not only represented by the weight of the body sustained by the foot, but that it requires greater effort to elevate and push forward the body in connection with the walking movements. The motion of the legs produces a reaction upon the body trunk, these reactions being effective in all directions, so that there are involved a number of very complex movements.

Body displacements have been estimated almost entirely from the center of gravity. This center of gravity is found to change when the body moves, so that it does not represent a perfect means of considering body displacement. In the bending of the legs the center is raised; in the motion of the arm it is also changed; and hence it is impossible to keep this as an ideal point, because it is continually moving. Hence there has been chosen a different part of the body, viz.: the pubis, by some experimenters as the point of the body in connection with which body displacements are considered. These displacements have been studied by means of the lever drums. In walking a person follows during the time of walking a circular or elliptical pathway, so that as he carries the instrument he is able to get a tracing to represent the vertical oscillations of the pubis. It is found that the pubis is raised at the middle of the pressure point period exterted by each foot and that the pubis falls when the body weight is passed from one foot to another. When the body weight is about to be transferred from one limb to another the one limb is in a slanting position, so that the upper extremity is at a less height than the other extremity. The other limb, as it reaches

the ground at this period, is slightly flexed, drawing itself up and then supporting the body. In this movement the leg that is moved passes through the arc of a circle around about the foot resting on the ground. Hence as these positions are changed, the body is raised gradually, as the leg to which its weight is handed over comes to the vertical position, falling down again as the same leg deviates from the vertical position. As the steps increase in length the body trunk is lowered on account of the increase of the obliquity of the leg. In connection with the horizontal oscillations of the body the pubis moves from left to right and vice versa while it is moving vertically. These movements may be recorded so as to find out the vertical and horizontal oscillations. It is found that the number of oscillations horizontally is about half the number of the vertical oscillations. This indicates that the body trunk moves to the right when the maximum of elevation of the body trunk takes place, and to the left at the period which corresponds with the middle of the pressure in connection with the left foot. This lateral movement of the body trunk results from the passage of the body alternately to a vertical position over each foot. Hence we have two kinds of oscillations, the vertical and the horizontal. During the act of walking there is a continuous advance of the body, although this advancement does not take place at a uniform rate. Hence we find in the forward movement acceleration and diminution in the velocity, these variations being found in connection with the different phases of the locomotive action. This inequality in the velocity involves a number of important consequences. When an individual pulls a load there is not a constant effort. As the foot comes into contact with the ground there is an increase of energy, and as this increase represents only a small part of the period that is associated with the traction, we have, as it were, slight shocks which are unfavorable to the perfect adaptation of mechanical energy. These shocks may be felt upon the shoulders if the individual is rigidly attached to the load. This forms the basis of some apparati that have been invented in connection with the traction of carriages by horses, so as to diminish the amount of shock and to enable us to utilize the full force of the horse.

Walking varies according to the character of the ground over which the individual walks. Some instruments have been invented with the object of indicating the variations in movement depending upon the sloping character of the ground. These instruments, as we have said already, were invented by Marey, with the object of finding out the pressure of the feet on the ground and also the vertical reactions imparted to the body by means of those pressures. Shoes are fitted to the runner's feet, while he holds in his hand a recording instrument which traces out the curves that represent the pressure of the feet. As the cylinder moves uniformly the curves will register the time rather than the space. A similar apparatus is attached to the head, so that the vertical reaction may be obtained in the form of a tracing. As the body oscillates vertically there is a piece of lead that resists these movements and causes the membran to fall as the body rises and to rise as the body falls. Thus there is produced an inner current which, when it is passed through a tube to the recording instrument, gives us the curve of oscillation. Thus we find curves representing the pressure of the feet upon the ground, and other curves representing the vertical reactions of the body.

This mechanism has been applied, (1) in registering walking movements. The body in walking does not leave the ground, the feet following each other without any intermission, so that the body work is passed from one foot to the other. This is not true in the case of walking up an inclined surface. In this

case it is found that the curves overlap each other, indicating that each foot still presses on the ground when the other has placed itself on the next step. In addition to this it is at the moment of double pressure that the foot which is lower exerts its maximum force, indicating that it is at this period the energy is utilized in raising the body. (2) It is also applied in the case of running. In this case there is a more rapid forward movement, while at the same time we have the alternate movements of the two feet, with this difference, that in the case of running the body does not rest upon the ground for a short period at each step. There are different forms of running, but these are not of importance physiologically. It is found that pressure of the feet in running is greater than that in walking, on account of the fact that in addition to bearing up the body the body is propelled forward and upward with a certain velocity. Hence the pressure must be greater. At the same time the duration of the pressure upon the ground is shorter, this shortness of duration being in proportion to the energy with which the feet tread on the ground. Hence the force and the shortness of the duration of pressure are increased as the speed is increased. The chief point in connection with running is the period when the body is not resting upon the ground, but remains suspended in the air between the two footfalls. The duration of this suspension does not vary to any great extent. It would seem that this suspension of the body depends upon the forward movement, of the nature of a leap, but this is found to be an untrue statement of facts. In accordance with the tracings it is found that the body performs its vertical risings during the time when the pressure of the foot is downward, so that the body begins to rise as soon as the ground is touched by the foot, reaches its maximum at the middle of the foot pressure and then again begins to descend. The time of suspension does not depend on the fact that the body is thrown up from the ground, but upon the fact that by the flexion of the legs the legs have been themselves taken from the ground. This takes place when the body stands at its greatest elevation from the ground. (3) In leaping, although it does not represent a regular movement associated with human locomotion, we have the two feet united together and making a series of leaps. It is usually supposed that we find a case in connection with a series of movements which take place between the action of one foot and the action of another foot. Hence a pace is usually measured by measuring the length of the distance separating one part of the print of one foot from a similar part of the print of another foot. According to Marey this definition of a pace is incorrect, because he claims that this represents only a half pace, defining a pace as "the series of movements executed between two similar positions of the same foot."

In connection with the different attitudes of the body we may notice the sitting posture. Sitting represents the position of equilibrium in which the body is borne up on the tubera ischii, so that it is possible to move the body back and forward on this base. The head and the trunk become rigid in order to the formation of a steady column. In the sitting posture there are said to be three attitudes: (1) the forward attitude, representing the line of gravity as passing posterior to the tubera ischii. In this case the body is supported by some fixture. (2) The backward attitude; in this case the line of gravity being posterior to the tubera-ischii. In this case the body is prevented from falling completely backward by some support or by the extension of the leg in connection with muscular action. In the last case the sacrum becomes a basis of support, the trunk being fixed upon the thigh and the leg extended. Here the center of gravity is so fixed that the foot assists in supporting the body. (3) In the sitting posture the

gravity line passes between the tubera ischii. If the leg muscles are in a condition of relaxation a slight muscular action can keep the trunk in a rigid condition, the head being balanced so as to maintain the uniform equilibrium of the body.

CHAPTER XIII. REPRODUCTION.

SECTION I.—Introduction.

There is not only the power of maintaining an independent existence in connection with nutrition and the other fuctions of the muscular and nervous mechanism, but also the power of reproducing life after its own kind. Man is to be regarded not only as an individual organism, but he is to be regarded as forming a part of a race, and as the perpetuation of the race takes place in connection with the production of new organisms the reproductive function represents one of the most important physiological functions. The reproductive function cannot be said to be limited to the independent life of an independent organism, but relates, rather, to the species, life. In this sense reproduction, physiologically, has not only a bearing upon sex and the reproduction of the saxes, but includes at the same time the whole field of embryology, which is too large to be discussed here from the standpoint of physiology. Reproduction involves the separation from the parent organism of a part of its own substance in the formation of an independent organism.

The process of reproduction is associated either with the sexual or the asexual methods. It has been claimed by some that by spontaneous generation it is possible that new forms of life may be originated without any parent germs of life. There seems, however, to be no evidence that if the living germs are excluded from either air or water there can be any possible germination of life. In connection with water and air we find numberless forms of life which may multiply beyond all possible conception. Whether spontaneous generation is possible or not it is not a subject that can be discussed from a physiological standpoint.

Of the two methods of reproduction the asexual is supposed to be the most primitive form and the sexual a later form which has been developed from the asexual. The asexual method of reproduction or agamogenesis is the chief form of unicellar plant, and animal reproduction by budding, fission and endogeneous cell or spora formation, the most simple forms being by fission or division. In the amoeba the cell protoplasm, including a nucleus, is divided equally, the separation of the two parts resulting in two independent nucleated organisms. In this process there is nothing lost, because the original matter of the cell is divided into two, becoming two offspring which, by increasing the size of the cells, become ultimately parents. This method of reproduction is found to exist even where the sexual method prevails in connection with the cell multiplication. The growth of an embryo really takes place by asexual development in the cells, these cells, being combined together in the formation of a separate individual. In this case the cells do not separate from one another in the formation of independent organisms, but are associated together very closely in constituting a single organism. The same asexual method of reproduction is found in adult life in the development of the blood corpuscles as well as in the regeneration of disintegrated or injured tissues. According to Spencer the asexual method of reproduction represents a discontinuous growth. In the case of pathogenesis there may be the reproduction of offspring different from the parent without any

of the sexual elements. This is found in connection with the development of the medusae. In this case we find that sexual union forms the basis, not of a single reproduction, but of the reproduction of several generations, some of which may be like and some unlike the parent form. In the case of the bees we find this pathogenesis, the queen bee having fully developed sexual organs, the male bee having also organs and the female working bees having imperfectly developed sexual organs. During the hiving process the union of the drone and the queen takes place, the queen placing an egg in a large comb cell and also placing some spermatic fluid in the cells. In small cells the eggs are placed within the fluid; in the latter case the drone bees are developed, and by the special nutrition of a working bee the working bee may become a queen and also produce other bees. By the special feeding of this working bee the sexual organs may become fully developed, and thus the worker may become a queen.

Among the higher animals reproduction results from the union of the male and female elements. These elements represent the differentiated parts of the body of the two sexes, the union of which represents the potential activity that is associated with the development of a new organism. This union of the two elements may be found in connection with the same body organism, as in the hermaphroditic animals, as the mollusc, but in all of the higher animals these elements are found associated with different organisms. This form of reproduction, called gamogenisis, is found in connection with some unicellar forms and most of the multicellar forms of life. In connection with the heteromita we have the perfect union of two bodies, this united mass being divided into a number of particles, each of these particles developing into an independent organism. In some of the higher infusoria there is a temporary union of two individual elements followed by a division, each of the separated parts developing an independent life: In the more highly developed animal forms, including man, we find the two sexes, sex representing a very important physiological difference: in each sex there are two kinds of cells, the germ cells and the body cells, the former representing nutrition, including all of the normal functions that we found associated with the individual organism, and the latter representing reproduction. These germ cells are spermatozoa in the male, which are small, and the ova in the female, which are larger and much more passive than the spermatozoa. Reproduction consists of the blending of the nuclei of the male and female germ cells; thereafter, by the process of asexual reproduction, cell division taking place. Thus after the sexual union takes place the progress of the newly originated life form is developed by asexual division. As to the production of sexuality very little is known. It seems to be an essential principle of all forms of life that reproduction is necessary to the perpetuation of the species. Spencer has pointed out that when a cell is growing there is an increase in the mass of the cell in the ratio of the cube, whereas the increase in the surface of the cells is in the proportion of the square of the diameter. This indicates that the mass of the cell increases much more quickly than the cell surface. This seems to indicate that as the organism develops it will reach a stage when the cell will be incapable of taking up a sufficient quantity of nourishment to sustain the substance of the cell. Hence, in order to the nutrition of the cell substance, fission becomes necessary, which simply means that a point is reached beyond which independent nutrition is impossible, so that the sexual method of reproduction is based upon the necessity for nutritive growth. Thus the blending of the cells and their separation is for the purpose of renewing the living substance from the standpoint of nutrition. It is much more difficult to account for

the sexual method of introduction, because we must account for not only the origin of an independent life, but also the origin of independent sexual life and the union of the male and female germ cells in order to account for the sexuality of the independent organism. We are not able to say whether sexuality is a primary quality of the protoplasmic substance or whether it is an acquired property. It is generally claimed that the asexual reproduction is the primitive form, on account of the fact that we find it so prevalent among the primitive forms of life. The sexual method of reproduction is found very generally among the different forms of life, indicating that the difference of sexes and also the process of sexual reproduction represents an essential quality associated with certain organisms. Different theories have been formulated in regard to the origin of sex. According to Hensen the union of cells that is found in connection with the sexual method is for the purpose of renovating the living substance. Asexual reproduction is circumscribed on account of the fact that by division and subdivision the asexual power of the cells become weakened, and in order to assist in the process of regeneration, the introduction of the new germ plasm requires to take place. This view has been defended by various biologists on the ground that if sexual union is prevented there is an atrophied condition of the organism with a corresponding physiological debilitation, representing the senility that precedes death. Another theory, defended by Hertwig, is that sexual reproduction hinders variation, and thus assists in maintaining the uniformity of the race. Hence, although the union of different parents produces variation, it tends to lessen the variation by the production of a mean between the two parents. In this way sexual reproduction produces variation, and at the same time destroys those variations, by preventing either extreme from becoming pronounced. Weismann's theory is the opposite of this, as he claims that variation is produced by sexual reproduction, these varieties by natural selection contributing to the production of individual characteristics. It would seem that the theory of Weismann may be associated with that of Hertwig, the former representing the individual variation and the latter representing the special uniformity. In both cases the reproduction process emphasizes variations. It is possible that in the perpetuation of the reproduction process some variation may be intensified and others destroyed to such an extent that there is produced the balance between the individual and the species. In connection with the individual organism we find that many parts of the organism can reproduce themselves: in other words, they are capable of regeneration. All of the tissues of the body, to a certain extent, do pass through these regeneration processes, the blood corpuscles, the muscles, the nerves, and even the bones being renewed. It is claimed that in the case of cartilage there is no such renewal, but this represents an exception to the general rule regarding regeneration. In some of the higher animals we find the regeneration of entire organs. This is illustrated in the regeneration of the digits of the newt, when these have been obliterated or destroyed. In connection with the human species the sexual characters have been divided into two classes, the primary and the secondary, the former referring to the sexual organs and their function, the latter representing the peculiarities that are associated with the different sexes, such as the relative size of the male and female body, the relative depth of the male voice as compared with the female voice. These secondary characters are dependent upon the primary characters, the primary characters being associated with the male organs and the female organs and the functions that are discharged by these organs. The sexual organs are sometimes classified as essential and accessory, the former in

the male being the testes and in the female the ovaries: while the latter in the male include the vasa deferentia, the seminal vessicles, the urethra, the penis, the prostate glands, the cowper's gland and the scrotum: in the female the accessory organs are the Fallopian tubes, the uterus, the vagina, the vulva and the mammary glands.

SECTION II.—The Male Organs of Reproduction.

The essential organs in the male consist of the two testes representing complex tubular glands enclosed in a strong covering. This covering from above and behind develops a tissue mass called the mediastinum testes. In connection with this covering we find a number of septa which separate the testes into a number of lobules. These septa consist of connective tissue. The minute testicular tubes consist of three parts, the tubuli contorti, small convoluted tubules which pass into the tubuli recti, which are narrow tubes that pass into the corpus in the formation of the rete testis, whose canals are very small in their diameter. The wall that is found in connection with the small convoluted tubes gives us a layer of connective tissue, a delicate membrane and a layer of epithelial cells, which vary in connection with functional activity. These epithelial cells, in a state of rest, are found to consist of several layers, while in a state of activity there is an increase of the cuclei, during which the spermatozoa are developed. The spermatozoid head corresponds with the nucleus of a cell. In connection with the epithelial cells we find round cells and the seminal cells, which, when they are active, become elongated, the nuclei being subdivided. At this point the cell has been called spermatogemma. The end of the cell branches outward, the minute nuclei representing the heads of the spermatozoid. As these separate from one another we find the formation of the spermatozoa.

The prostate gland is a glandular substance and also unstriped muscle substance, the gland cells being short and the muscle being found in large quantities between the gland acini. The corpus glands are also acinous, having large vesicles. In the penis we find three cylindrical bodies, two corpora cavernosa and one corpus cavernosum urethrae. The glans penis consists of veins very much convoluted, connected together by means of connective tissue, in which we find small arteries and capillaries.

The essential function of these organs is the formation of the spermatozoa and the fluid in which the spermatozoa lives and moves, and they are also connected with the storage and the ejection of the seminal fluid. The spermatozoa were for a long time considered a form of parasite. They have been found to consist of cells that are elongated for locomotion. They consist of a head, a central part, and a tail about one-four hundred and fiftieth part of an inch in thickness. The head is a thin oval body, the central part is a plasmic or rod-like structure in which we find a centrosome, and the tail is a fibrillary plasmic substance of cilia structure. At the tip of the tail we find a very deliate filamentous structure. The chief composition of the spermatozoa is represented by nuclein which is found associated with the head, together with proteids, lecithin, cholesterin and fat. The spermatozoon is very active in form and movement, being specially modified in form for fecundation in connection with the ovum. Fecundation takes place in connection with the nucleus. The head is specially adapted for seeking entrance into the ovum, while the locomotion is accomplished by the lashing movement of the tail, accompanied by rotation, which takes place at the rate of two or three milimeters per minute. The production

of the spermatozoa is very rapid, and they are produced in large numbers, it being estimated that over 200,000,000 are produced per week in the normal adult. These spermatozoa can live for a long time in a quiescent condition, having been preserved alive for two days outside of the human body. The excess of production makes it possible for the fecundation to take place in connection with the ovum. If they did not exist in large numbers fecundation might not take place. These spermatozoa arise in connection with the division of the testicular cells, sometimes called the mother cells, these developing spermatozoa by a process of division. In the human subject each primary mother cell gives origin to four spermatids, these directly growing into the spermatozoa.

Much discussion has taken place in regard to the process of maturation. It has been found that the chromosomes, in connection with the nucleus of a spermatozoon, is only about half that found in the primary testicular cell, representing the fact that the chromosomes are reduced by about one-half. This has been found to be the case in the human spermatozoa. These chromosomes represent, according to the Weissmann theory, the source of hereditary transmission, and indicate, as it is claimed, the division of the chromatic substances, so as to reduce the hereditary substance. In connection with the maturation of the ovum there is a similar reduction, so that in the process of union between the spermatozoon and the ovum there is compensation for the loss of the individual chromosomes.

The semen, which consists of the spermatozoon and the fluid which arises in connection with the testes and the vasa-deferentia, the seminal vesicles, Cowper's glands and the prostate glands, is a viscous white fluid, with a characteristic odor. In addition to water, representing about eighty percent, it contains solid matter, including nuclein, proteids, lecithin, anthin, cholesterin, fats and the sodium and potassium chlorides, as well as the sulphates and phosphates. In connection with the semen there are found the phosphate crystals called Charcot's crystals. The chemical characteristics of the semen are not of importance as compared with the histological and physiological properties. The seminal fluid is chiefly of value as the medium of transmission for the spermatozoa and for their nutrition. The testes cells furnish some of the nutritive matter of the fluid, the secretions of the prostatic, the seminal vesicles and the other glands being necessary in order to the mobility, as well as the nutrition, of the spermatozoa. The prostatic secretion is viscid, the solids being chiefly proteids and salts; the seminal vesicle secretion is albuminous, containing fibrinogen to assist in the coagulation of the fluid, and thus prevent the spermatozoa being lost; the Cowper's gland secretion is mucous in its nature. The testes represent compound tubular glands, appearing in the early embryonic life in solid form, with small tubules; at the time of puberty the cells begin to divide in the formation of the spermatozoa. As the spermatozoa are formed they pass to the center of the tubules, leaving miniature cells along the walls, representing the immaturity of spermatozoa. Other cells distintegrate in the formation of the nutritive fluid, in connection with which we find minute granules or particles. This cell activity goes on from puberty during the active secretion of the seminal fluid, the secretion depending, to a certain extent, upon the discharge of semen. The spermatozoa are found to accumulate inside the seminal tubules and are pressed out by the formation of new spermatozoa. The testicular ducts consist of very long tubules, the tubuli recti, rete vasculosum, vasa efferentia, epididymis, the vas deferens and the ejaculatory duct, forming passages for the passage of the fluid. The first two simply represent channels along which the spermatozoa

pass. The vasa efferentia and epididymis canal, with smooth muscular tissue and epithelial ciala, furnish a smooth surface for the movement outward of the spermatozoa. The vasa deferens, or excretory duct, with its branching visicle, represents the excretory organ. In the vas deferens there is a storage of the spermatozoa, the glands providing a secretion and the muscular walls assisting in the ejection. The seminal vesicle furnishes the greater part of the fluid secretion. The ejaculatory ducts pass through the prostate glands, carrying the semen to the urethra. The urethra represents the common excretory duct in connection with the urine and semen, consisting of the prostatic, as well as the membranous and spongiose parts. In connection with the first we find the prostate gland, which is a compound tubular gland surrounding the urethra at the base of the bladder, into which it opens by a number of minute ducts. It furnishes prostatic fluid to the semen. The Cowper's glands are racemose in character, the ducts opening into the spongiose part of the urethra. These glands furnish a viscid secretion which is mixed with the seminal fluid, although, according to some, the Cowper's gland secretion is a lubricant for the urethra. The spongy parts of the urethra are associated with the penis. The penis forms the channel of conveying the semen, as the intromittent organ, its rectile function being dependent upon the erectile tissue, which constitutes the greater part of its structure. This erectile tissue is found in connection with three tissue masses, the two corpora cavernosa being found at the sides and being united at the upper part of the penis; the corpus spongiosum being found in the middle line beneath and being penetrated by the urethra. In connection with the muscular extremities of the corpora we find bulbous portions covered over with muscular fibres, the ischio cavernosi being found in connection with the corpora-cavernosa and the bulbo-cavernosus in connection with the corpus spongiosum. At the peripheral end of each corpus there is a blood termination, the corpus spongiosum projecting peripherally in the formation of the glands penis.

The erectile tissue consists of irregularly shaped trabecula, in connection with the connective tissue, abundantly supplied by elastic tissues and also plain muscle tissues. The trabecular spaces are filled with spindle-formed plates, representing venous sinuses, into which the blood passes, chiefly in connection with the terminal capillaries that are found in the trabecula, and also directly in connection with the arteries. When the branches of the pudic arteries and the dorsal arteries of the penis become constricted the venous spaces are closed to a large extent, the most of the blood passing through the arteries passing by the ordinary capillaries into the veins, the venous sinuses being practically empty. By the dilatation of the arteries there is a large quantity of blood passed into the venous sinuses, with the result that distention takes place in connection with the erectile tissue. In connection with the dog and cat we find fibres from the anterior roots of the first, second and third sacral nerves, constituting the nervi erigentes, which are distributed to the penis in connection with the pelvic plexus; in the monkey the nerve fibres spring from the seventh lumbar and the first and second sacral nerves. These represent the erectile fibres in connection with the penis, their action being vaso dilator, resulting in the dilatation of the arteries. Erectile action is not entirely dilatation, because the dilatation of the arteries is assisted by the relaxation that takes place in the trabecular muscle fibre. In addition to this the blood, as it fills the venous sinuses, presses upon the large veins, thus increasing the distended condition, and the contraction of the muscles between which the veins pass assist in preventing the outflow of blood. This dilatation, associated with the nervi erigentes, may be stimulated reflexly

by the stimulation of the glans penis, the center of this reflex action being found in the lumbar region of the spinal cord. The action is not purely reflex, as erection may also take place as the result of psychic emotions which originate impulses that pass down to the lumbar centers. The act of erection and the consequent seminal ejection takes place in connection with a number of actions. The epididymis represents a store-house of seminal fluid. The beginning of the action is represented by secretory activity in the seminal tubes, increasing the amount of fluid found in the epididymis. Then follows the propulsion of the fluid that is found in the epididymis by peristaltic action, passing along the tubular walls. This secretory fluid is carried to the vas deferens, and by peristaltic action passes along this tube. The result of this is that the seminal vesicles become filled, and thus distended, the distention being followed by a strong contraction of the vas deferens and the seminal vesicles, with the result that the fluid is ejected into the prostatic urethra. Then follows the contraction of the prostate fibres, producing the ejection of the prostate secretion into the canal of the urethra. Here the action of the unstriped muscle fibres, in their peristaltic action, cease, and we have the action of the striped muscle, by the powerful contraction of the levator ani, the Constrictor Urethrae, Ischiocavernosus muscle and the Bulbo-Cavernosus muscle. The contraction passes in a wave-like manner from the posterior to the anterior, continuing rhythmically until the semen is driven out into the urethra. These powerful contractions are at least assisted, if not produced, by reflex action in connection with the lumbar region of the spinal cord, the afferent impulses originating from the sensory surface of the glans penis. When the semen is discharged into the vagina the vaginal walls are in a condition of dilatation, and it passes to the upper end of the vagina, where there is found a cavity in connection with the os uteri. In this way the spermatozoa are brought into connection with the uterus and the Fallopian tube, where they are brought into contact with the ovum. The passage of the spermatozoa takes place largely on the basis of vibratile action, although in some animals there is a backward peristaltic movement of the uterus along the Fallopian tubes, which assists in the coition of the spamatozoa and the ovum.

SECTION III.—The Female Organs of Reproduction.

The ovaries in the female are found to consist of glandular substance and connective tissue. Externally there is a fibrous tunic, consisting of connective tissue bundles; then we find a cortical substance, in connection with which we find the glands, and internally we find a medullary substance, in connection with which we find smooth muscle fibres. In the maturation of the Graafian vesicle it breaks next to the ovarian surface, the ovum passing into the Fallopian tube. The vesicle, when emptied, becomes the corpus luteum, and if impregnation does not take place there is the disappearance of the corpus luteum, while if pregnancy takes place there is the formation of the true corpus luteum. The formation of the true corpus luteum takes place in connection with fibrous membrane, in connection with cell proliferation of the membrana granulosa. The connective tissue is formed in connection with the blood clot that is derived from the breaking of the vessels, the membrana cells proliferating. The ovarian arteries, which branch from the internal spermatic, pass into the hilum and then divide in the medullary substance, running in a convoluted path into the cortical substance, forming plexuses. The veins are found near to the hilum in a dense plexus. In the Fallopian tube we find

three membranes, a mucous on the internal, a muscular in the middle, and a serous on the external surface. The internal membrane is folded longitudinally, the folds being greatest at the upper extremities of the tubes, forming the fimbriated ends. The uterine wall has a mucous membrane, a muscular tissue and a serous membrane covering. The membrana propria consists of connective tissue connected together, in the midst of the fibres being found many white corpuscles and also tubular glands. The muscular coat consists of smooth muscle fibres, in the midst of which there are interwoven three strata. In connection with the cervix uteri we find a thicker mucous membrane and also papillae covered over with tesselated epithelium. We also find mucous glands which are filled with a secretion called the glands of Naboth. During the period of menstruation the mucous membrane is thickened, on account of the increase of the interstitial substance and the number of leucosites, the glands being also increased and the blood-vessels dilated. When pregnancy takes place the mucous membrane is thickened, and the muscular layers also become considerably thickened.

In the vagina we find a mucous, a muscular and a fibrous coating. In the mucous membrane we find papillae, with a delicate membrane of connective tissue, the leucosites being found in connection with the epithelial cells. There are no glands found in connection with these coatings, the capillary blood vessels being found in the mucous and submucous coating, and the veins in connection with the muscle fibres. Around the clitoris and the urethral opening we find mucous glands, and in connection with the labia minora we find sebaceous glands, the structure of the clitoris being analogous to that of the skin. The vaginal secretion is found to contain epithelial cells, white corpuscles, and sometimes a pathological parasitic worm called trichomonas vaginalis.

The chief function of the female reproductive organs is the formation of the female germ cells, called the ova, their conveyance to the uterus, and when fecundated, the protection and sustenance of the embryo during its intra-uterine life and its final delivery at birth. The human ovum represents a rounded cell of protoplasm about one-twenty-fifth of an inch in diameter. The nucleus is distinct from the cell body, which consists of a very fine framework of protoplasm externally clear and transparent, internally, towards the center, dense and dark, on account of the presence of the deutoplasmic substance, which furnishes a nutriment to the embryo. The external protoplasm is called cytoplasm, the cytoplasm consisting of a very delicate protoplasm. Close to the nucleus we find a differentiated substance, consisting of the centrosome. The nucleus, or germinal vesicle, is spherical, and exists away from the center, being limited by the nuclear membrane. The protoplasm is said to consist of two kinds of substance, the one chromatic and the other achromatic. The latter is said to be the same as the cytoplasm. The chromatic substance is associated with the nucleus, and as it passes through certain stages becomes chromosome. It is in connection with the chromatic substance that the transmission of germinal life takes place. The nucleus is found to be limited by a membrane, and contains a nucleolus which is called, sometimes, the germinal spot. The ovum is found to be surrounded by a thick membrane called the zona pellucida, in connection with which radiation takes place to the ovum, these radiating lines representing pores, and thus forming media of communication between the nutriment and the germinal substance. In connection with the external portions of the zona pellucida we find cells that are derived from the Graafian follicle, constituting a complete covering.

Nothing is known, definitely, of the chemical composition of the human ovum. The protoplasm is said to be undifferentiated, consisting of proteid substances, whereas the deutoplasm represents the food substance, consisting of vitellin, nuclein, salts, fats, etc. The ovum, in connection with fecundation, is passive, the nucleus being combined with the nucleus of the spermatazoon, the larger part of the ovum representing the nutrition of the combined spermatazoon and ovum. In the maturation of the ovum the process is analogous of the spermatozoon, taking place as the ovum leaves the ovary. This takes place by karyokinesis of the nucleus, very similar to, if not the same as, the karyokinesis of the ordinary cell. The nucleus moves outward towards the surface, the cytoplasm divides into two parts, being arranged on either side of the nucleus, the substance between being formed into a filamentous shape, the nucleus being divided into two parts, representing two polar bodies that have no special function in connection with the ovum. This involves the reduction of the chromatic substance so as to prepare it for union with the male germ cell, maturation in both cases being a preparation for this union of the male and female germ cells. The maturation of the ovum differs from that of the spermatozoon, because in the latter case the primitive mother cell is divided into four spermatozoa, while in the latter case the primitive mother cell is divided into two polar bodies which have no special function, and one ovum which is functional. The two processes, however, are essentially the same, the aim in both cases being to reduce the chromatic substance in connection with the nucleus. In the ovum maturation the chromosomes are divided in two, and the number of germ cells is the same. The matured cell, although it is a cell, is incomplete, the completion taking place in connection with the fecundation process, when the chromosomes, which in the somatic cells have been divided in two to form the germ cells, are restored to their normal number by the union of the male and female germ cells. In this way the chromatic substance of the two germ cells represents the male and female elements that are associated with the reproduction of life. According to Weissmann this maturation process is essential in order to prevent the increase of these hereditary elements, which would take place if such a division did not take place in the reduction of the chromatic cell substance; thus the process of maturation prepares the germ cells for union in the formation of the germ of the newly developed life.

The ovaries are somtimes called glands, but they represent a solid structure, consisting of a framework of connective tissue with connective tissue cells, the ova being produced in connection with these ovaries. The development of the ova takes place in the Graafian follicles, the development taking place from primary ova which represent modified cells, in connection with the epithelial germ. In the human ovary it is esimated that after puberty there are 70,000 ova, these representing modifications of the germinal epithelium, while the development takes place in the Graafian follicles. These Graafian follicles are found to be lined by epithelial layers, and it is filled with a fluid called the liquor folliculi. As the development takes place the Graafian follicle comes to the surface of the ovary, and rupture takes place in the follicle wall when ready for discharge, the ovum being thrown upon the ovary surface, to be taken up by the Fallopian tubes. The ovum discharge is called the ovulation. The follicles, when emptied, become the copus luteum, which degenerates and disappears, unless fecundation follows, when it increases in connection with pregnancy, and remains in this enlarged condition before degeneration sets in.

Some physiologists claim that ovulation accompanies menstruation, but it does not seem to be limited to the menstrual period. It would seem, however, that ovulation at the menstrual period is more characteristic than at the intermenstrual periods. These Graafian follicles are found to develop even before puberty, some cases being on record in which ovulation is found during childhood. The ovulation usually begins about the period of puberty in connection with menstruation. It is supposed by most physiologists that ovulation is suspended during the period of pregnancy, and some claim also during the period of lactation; there is, however, evidence that during the lactation period ovulation may take place. In the Fallopian tubes we find two layers of plain muscle, an external longitudinal and an internal circular, the two being lined with cilia, in connection with which movements take place towards the uterus. The chief function of the Fallopian tubes is to furnish the channel for the passage of the ova to the uterus and the spermatozoa to the ovary. After ovulation there is a slight adherence of the ovum to the ovary centers in connection with the liquor folliculi. It is claimed by some that the enlarged end of the Fallopian tube firmly lays hold of the ovary, the ovum being discharged into the tube in connection with the fimbriated cilia, the cilia in the tube in connection with muscular contraction carrying the ovum towards the uterus. The uterus receives the ovum as it passes from the Fallopian tube, and it, unfecundated, passes into the vagina. It also receives from the vagina the spermatozoa and sends them on to the Falloapian tube. The uterus represents the menstrual change, and when fecundation takes place the uterine germ is developed and nourished within the uterus until its expulsion takes place from the uterus. Hence, when fecundation has taken place the uterus holds the embryo until the close of the uterine life. It consists of three layers of muscles, the outer and middle coats being thin, the inner layer forming the chief part of the uterine wall. The fibres are circular, at the upper part becoming transverse in connection with the Fallopian tubes, and at the cervix circular fibres are found encasing longitudinal fibres. The mucous membrane represents a thick membrane in which are found a large number of glands that secrete a mucous substance. The tissue development takes place gradually until the period of puberty. The most important phenomenon connected with the female organ is associated with the menstruation change.

From about fifteen to seventeen years of age, representing the age of puberty, to forty-five years of age, the escape of an ovum from the ovary takes place monthly. Accompanying this change there are certain changes in the pelvic and uterine organs both of a local and general character. There is an increase in the size of the uterus associated with the increased flow of blood; the mucous membrane becomes thickened and some parts of the mucous membrane become separated, some of the capillaries being ruptured, producing a mixed fluid consisting of mucus and blood called menstrual fluid. The discharge may continue for three or four days, usually slight at the beginning, and becomes more abundant until it reaches a maximum and then slowly decreases. The amount of blood discharged varies from 100 to 200 grams. The blood arises from the ruptures of the blood-vessels of the uterine wall. During this period there is a large increase in the blood flow in the uterus. Along with this there is a disintegration of the epithelium, the blood being mixed freely with the mucous epithelial cells, the red corpuscles and the leucocytes. After the flow ceases the mucous membrane is repaired, there being a new growth of cells of capillaries and of glands. Accompanying these uterine changes are found a congested condition of the Fallopian tube and of the ovaries. It is generally believed that

ovulation accompanies these periodic changes. These are also accompanied by some characteristic signs, usually found in the swollen condition of the breast, the thyroid and the parotid glands, the dull and dark skin, and especially the dark color around the eyes. There is often mental and nervous excitement, together with feelings of pain in the back and the limbs, and sometimes sickness and vomiting. These changes, associated with menstruation, are evidences of physiological changes taking place in connection with the monthly period, so that the female organism is altered so as to accommodate itself to the uterine changes that take place in connection with the organism. In the intervals between the menstrual periods the nervous condition is improved, the vascular condition is also regenerated, and there is a gradual increase in the trophic condition of the system. These changes usually reach a maximum just before the beginning of the menstrual flow, and then, as the flow begins, the changes begin to give evidence of a fall, a minimum being reached towards the end of menstruation. There is thus found to be, in connection with the female organism, monthly rhythmical changes that are associated with the uterine changes. The beginning of menstruation is usually the indication of puberty, or the capacity of procreation. In temperate climates it usually occurs at fifteen or sixteen years; in tropical climates, from three to five years earlier, depending upon the growth and also the food. In normal conditions it ceases during pregnancy and also during lactation. In some exceptional cases menstruation begins even in childhood, and in some cases menstruation has been found to be entirely absent. By the entire removal of the ovaries, menstruation would cease. The cessation of menstruation indicates the climacteric period of life, usually ranging from forty-four to forty-eight years, the change taking place gradually. Accompanying this change there is also a series of body changes, the reverse of those taking place in connection with puberty. Ovulation and menstruation are largely independent, as they do not necessarily coexist. The uterine development prepares for the growth of the embryo. When an ovum is discharged and becomes fecundated, it is attached to the uterine wall, and a pregnant condition follows. If fecundation does not take place, then we find tissue degeneration, and the discharge takes place. In the escape of an ovum from the Graafian vesicle, it passes into the fimbriated end of the Fallopian tube. The ovum passes along the tube by a ciliary movement, and in connection with muscular peristalsis.

Several theories have been formulated in regard to menstruation, all of them agreeing, more or less, in this: that it is associated with the function of reproduction. The oldest theory represented menstruation as an outflow of superfluous nutrient fluid. Pfluger formulated a theory to account for menstruation, claiming that it took place in order to remove the older and exhausted parts of the uterine walls, in order to prepare a new surface for the ovum when fecundated. In connection with the development of the ovarian cells and the dilatation of the ovary, there is aroused a stimulus, which is communicated to the ovarian nerves. In connection with these stimuli there is a dilatation of the blood vessels, the excessive supply of blood producing rupture of the follicle. Hence menstruation and ovulation represent the same producing cause. According to this theory we can easily account for the absence of menstruation when the ovaries have been removed. Modern theories have been formulated to account for the changes that take place, the tendency in modern times being to regard ovulation and the menstruation as being independent; the uterine development represents the preparation for the embryonic germ. Hence the decidua menstrualis prepares the way for the decidua graviditatis. When an ovum is fecundated

it becomes attached to the uterine wall, pregnancy results, and the decidua is retained until the time when the parturition period approaches. If the fecundation does not take place there is no attachment to the uterine wall, the tissues degenerate and are discharged in connection with the menstrual flow. Jacobi considers menstruation as the physiological homologue of parturition. It is said to be primarily derived from the periodical change in condition found in the lower forms of life. This represents something that is inherited from more primitive forms of life. In these primitive forms of life we find what are called reproductive, or seasonal, sexual periods, sexual activity taking place during those specific seasons. Civilization, applied to the human subject, has largely modified this original natural endowment. In line with this it is claimed that the reproductive periods have become more frequent, and that the frequency of the menstrual periods represents the homologue of these increased reproductive periods. Here we have a modification of the reproductive function, associated with the upward evolution of the human species. In connection with the reproductive organs it ought to be noticed that they are not quiescent, but are really associated with an internal secretion. It is claimed by some that the removal of the testes or the ovaries is not accompanied by great body changes; at the same time, the removal of these organs produces characteristic changes, both in connection with the male and the female. This undoubtedly indicates that there is a reaction of the sexual organs upon the other organs of the body. It is possible that there is not only a chemical reaction, but also a nervous reaction. In regard to the chemical reaction, it has been shown that the injection of testicular extracts has a beneficial effect upon the system, indicating that there is an internal secretion associated with the reproductive organs, which is of value in the general metabolism of the body.

SECTION IV.—The Reproductive Functions.

The essential part in the process of reproduction is the blending of the two germ cells. Hence, in the reproductive process, we require to follow spermatozoa and the ova in their relations as germ cells. Originally, it is believed, the spermatozoa and the ova are similar cells, being modified during development, the one becoming an active and the other a passive cell; these modifications take place in connection with the cytoplasm, the nuclei in both cases remaining unchanged. The many processes that are involved in the reproductive function are simply for the purpose of bringing together these two chromatic substances, which represent the male and female germ elements.

The act of coition is the union of the two sexes in the passing of the seminal fluid from the male to the female. The penis becomes rigid and the bulbar organs become turgid. These are produced by vascular dilatation, due to the muscular and nervous impulses. The vascular changes are associated with nervous and muscular action. Erection is a reflex action, the center being in the lumbar region of the spinal cord, and it is aroused by psychic or tactile sensations, the center acting through the sacral nerves and the hypogastric plexus. From the first two sacral nerves arise the nervi erigentes. Impulses may originate in the brain and pass down along the spinal cord; they may also arise in the walls of the testicular duct, arising from the pressure of the semen, or from a sensory stimulation of the penis, impulses passing along the sensory nerves to the center. In the female, corresponding phenomena are associated with the female organs, the clitoris with the glans, and the corpora cavernosa correspond-

ing to the penis: the two bulbar vestibuli with the bulb of the corpus spongiosum, and the pars intermedia with the corpus spongiosum. The erectile mechanism in the female is analogous to the male. The semen is stored in the ducts of the testes; by the contraction of the seminal vesicles the fluid is passed out into the prostatic part of the urethra, from which it is driven out by the muscular contraction of the fibres around the bulbar portion of the urethra. It is mixed with the prostatic fluid, and the secretion of Cowper's glands, the prostatic expelling the fluid, the final urethral expulsion taking place in connection with the cavernosa constrictor urethrae and the anal muscles. In the female there is also a discharge taking place in connection with the Bartholini glands, which pour out a mucous fluid into the vulva. Accompanying this there is a downward movement of the uterus and a contraction of the uterine walls. The spermatozoa, by quick locomotion, make their way into the Fallopian tube, where the union takes place with the ovum. It is generally supposed that the uterine contraction sucks the fluid towards the uterus, which accounts for its passage through the os uteri and the cervix. This is aided by the vaginal walls contracting. These movements are assisted by the very active movements of the spermatozoa moving along the mucous surface, the ciliary movement being said to increase the spermatozoa activity. The movements are rapid, normally, as there seems to exist a selective affinity between the ova and the spermatozoa, possibly of a mechanical nature. In the maturation of the spermatozoa and the ova there is the loss of one-half of the chromosomes in connection with the nucleus in each case; after this maturity the fluid is pressed together in the Fallopian tube, the blending of the germ cells taking place into a single cell, forming the process of fecundation. At the period of fecundation the ovum is surrounded by the zona radiata, the corona radiata being lost. Around the zona the spermatozoa are found in rapid movement, attempting to pass through. The head and the central part of the spermatzoon being necessary to the fecundation of these parts, are reserved, while the tail, which seems to be unnececessary is permitted to be destroyed. The head makes its way to the center of the ovum, and by sucking out the fluid, becomes enlarged. The oval nucleus is found near the center of the ovum, where it meets the spermatozoon nucleus, the two nuclei being fused together in the formation of a new nucleus, called the first segmentation nucleus. This consists of a chromatic framework, in which is mingled the chromatic substance, the entire structure being covered with a nuclear membrane. This chromatic substance, half being derived from the sperm and half from the ovum, forms the hereditary substance, this containing all the hereditary qualities of the future individual. As the sperm head is passing through the ovum substance there gathers around it a cytoplasmic substance, the centrosome, around the centrosome being gathered the cytoplasmic substance forming the sperm star. The ovum plasm thus gathers around the centrosome in the shape of a star, its functional activity being associated with the polar bodies on either side of the nucleus in the maturation of the ovum. The entire body is called spermaster. It enlarges and is found in connection with the nucleus of segmentation. The centrosome is supposed to originate from the central part of the spermatozoon. This spermaster represents the resulting single cell, produced by the union of the primary nuclei, thus forming the origin of the individual life.

The growth of this part represents a complex process of segmentation, including cell division, growth, specialization. The early stages of ovum division are technically called segmentation, in the human subject. In segmentation

there are formed a large number of rounded bodies, the ovum being increased in size. Each division seems to be associated with three marked acts, which, however, cannot be absolutely distinguished from each other. (1) There appear two centrosomes instead of one, each one occupying a position on the opposite sides of the nucleus. According to some, these two centrosomes represent one the male and the other the female part of the germ, according to which hereditary qualities are transmitted by the nuclei and the psycheplasm. According to others, they arise from the central part of the spermatozoon, and are not connected in any way with hereditary transmission, the nucleus alone being the bearer of hereditary characteristics. (2) During the second stage the nucleus is divided, the nuclear membrane disappearing. The achromatic network becomes filamentous, arranged around the centrosomes The chromatic substance becomes arranged in rod-form chromosomes. The male and female chromosomes remain distinct, each chromosome dividing longitudinally, the two parts being drawn to the centrosomes. In the nuclear division the male and female elements are equally divided, and hence there is an equal inheritance of the parental characteristic. (3) The cytoplasm becomes divided into two parts, each part taking one of the nuclei, the two blastomere cells taking the place of the single ovum. Each blastomere then divides, by karyokinesis, again into two, with the result that there are four cells, this process of division going on so that there is developed a number of smaller cells, out of which the embryo is formed. By this process of segmentation the original fecundated ovum is divided up into a large number of smaller rounded bodies, the continued division and the consequent increase of cells forming the basis of the embryonic development and of the functional development of the embryo. While this is taking place the ovum is passing along the Fallopian tube, and goes into the uterus. At the center of the morula some fluid is collected, pressing down the cells towards the periphery, forming a sac-like structure, called the blastodermic vesicle. Some of the smaller segmentary cells gather together at one of the vesicle poles called the blastopore, in connection with which an elevation is formed, in which there is an indentation, the convexity being internally. At this point there is a double layer of cells, the external cells being the largest. Here is the embryonic area, in connection with which the embryo is formed. Those cells nearest to the zona form the epiblast, and the internal cells form the hypoblast. The hypoblastic cells increase quickly, constituting a layer lining the epiblast chiefly, near to the embryonic spot. The hypoblastic cells are small, slightly granular, while the epiblastic cells are larger and more granular. Around the embryonic spot the epiblast gradually increases, the epiblastic cells proliferating in the formation of an eminence. Out of the epiblast there is developed an intermediate layer of cells called the mesoblast. Out of these three layers all the tissue parts of the embryo are developed. The blastodermic vesicle is infolded in cup shape, the edges showing one layer within another, forming an outer epiblastic and an inner hypoblastic layer, and the cavity between the two representing the original segmentation cavity, or the primitive intestine, and its opening representing the original blastopore, or embryonic mouth. In connection with the embryonic spot there is a rapid proliferation, especially in connection with the periphery, the central part being clearer than the peripheral part. In the central area there is formed an elongated part, which becomes constricted at the middle. This represents the primitive plate, in the center of which we find the primitive groove. The edges of this groove form the medullary folds, in connection with which we find the medullary plates, which

in turn form the neural canal, in connection with which we have the development of the cerebro-spinal system and the special sense organs. Out of the medullary plate are developed the epidermal structures, including the glands, both mucous and serous. As the differentiation proceeds in connection with the mesderm, there is the appearance of a rod-like structure below the neural canal. Each part of the mesoderm is then divided into two logitudinal plates, the plate that is next to the central structure being called the vertebral plate, and the external part being called the lateral plate. The primitive plate is then divided transversely in the formation of the primitive vertebrae, out of which are developed the different parts of the vertebrae, the differentiation of the primitive vertebrae forming the basis of the original muscle development.

In connection with the lateral plates we find a development by horizontal segmentation of two plates, an external and an internal, the former representing the parietal mesoblastic layer, which is united with the epiblast, and the latter the visceral mesoblastic layer, which is united with the hypoblast. Close to the vertebrate plates is found a cavity between those two layers, which represents the origin of the pleural and peritoneal cavities. As the development proceeds the parietal and visceral layers of the mesoblast are divided in the formation of the body cavity, the former layer representing the body walls, and the latter layer the intestinal canal. There is a middle plate, which is found at the point where the visceral and parietal layers of the mesoblast come together, before they are distinctly separated in the formation of the body cavity; in the area around the middle plate, the vertebral plate and the epiblast, we find the Wolffian bodies, which represent the original form of the sexual and urinary organs. It is from the mesoderm that the blood-vessels are developed; even before the primitive appearance of the vertebrae, the blood-vessels are found in cellular cord form. Out of the visceral layer of the mesoblast is developed the heart, which at first represents a straight rod, and then afterwards becomes hollow and twisted. Out of the upper part of this twisted tube two aorta arise, which unite in the formation of a single vessel, out of which the two primitive aortas originate, each aorta giving off several arteries, in connection with which capillarity is developed, and the venous system, which is attached to the posterior portion of the cardiac tube. In connection with the hypoblast there appears the intestinal furrow, which is developed into a tube, as the margins coalesce. In connection with the tubular walls we find the connective tissue, and the vessels developed from the visceral layer of the mesoblast, the intestinal glands being derived from the hypoblast. Very soon there appears an opening at the middle of this intestinal tube, which is associated with the vitelline duct, in connection with which nutrition takes place. At this period the embryo is found to be lying with its face downward, upon the vitellus, the body cavity and the intestinal cavity being opened.

During the segmentation process in the Fallopian tube the uterus goes through a change, preparatory to the reception of the ovum, these changes taking place under the influences arising from the contact of the ovum with the walls of the tube. The uterus is enlarged, the mucous and the muscular coats becoming thicker. There is an increased blood supply to the walls, as well as an increased supply of lymph. The mucous coat becomes soft, a number of large cells being developed, called the decidual cells, these remaining and not falling away, as in the case of mestruation. When the ovum enters the uterus it becomes attached to the uterine wall, the portion of the mucous coating in which it is embedded being called the decidual serotina. This represents the future

placenta, and as such it represents the most important part of the uterine wall. The contiguous cells increase, and by increasing they surround the ovum with a layer called the decidua reflexa, the rest of the uterine mucous membrane being called the decidua vera. Lying between the vera and the reflexa we find the uterine cavity. The reflexa, from being thick, becomes thin, and approximates to the vera, being completely merged into the vera after the sixth month. As the embryo grows the vera becomes thinner. The ovum is nourished in connection with the maternal tissues, and in its later periods through the placenta. In development cell division takes place very actively, the vertebrate characteristics being developed as early as the thirtieth or fortieth day.

The embryo is encompassed by two foetal membranes, the amniotic and the chorionic, or false amniotic. Immediately around the embryo is the amnion, a very fine and non-vascular membrane. Later it is separated from the embryo, although in origin it is closely connected with the embryo. In the amniotic cavity there is the amniotic fluid. This fluid is said to be exuded from the embryonic and maternal blood, having from two to three per cent of solid matter in it, consisting of proteids, mucin and salts. It surrounds the whole of the embryo, sometimes passing into the foetal stomach. Its functions are to protect the body, preserve the normal temperature and keep the body moist; it is also said to be connected with nutrition and excretion, on account of the presence in it of the proteids and a small quantity of urea. The chorion is formed at the same time as the amnion, and from the same origin. It is thick and very vascular, completely encircling the amnion. Lying between the amnion and the chorion is the umbilical cord and the chorionic fluid. As the amnion enlarges the cavity is destroyed, the amnion disappearing. On the external surface of the chorion are villi passing out into the decidua reflexa and scrotina. Gradually these villi are obliterated, except in connection with the scrotina, forming a part of the placenta. The allantois develops from the posterior part, when fully developed, communicating with the intestines by means of the urachus. In connection with this cavity we find the allantoic fluid, with four or five per cent of solids, including allantoin, albumin, urea and salts, representing the embryonic excretion. The blood vessels of the chorion come from the allantois, forming the two uniting branches of the two umbilical arteries and the one umbilical vein. As the development takes place the chorion and the reflexa unite; the reflexa gradually disappears, the chorion being left as the frondosum. the decidua scrotina forms the maternal part of the placenta, the foetal portion being the chorion frondosum, the two, the chorion frondosum and the decidua scrotina forming the placenta.

The placenta is a disc-shaped mass, seven to eight inches in diameter, bound to the internal uterine wall, usually on the dorsal side, and bound by the umbilical cord to the foetus. The scrotina consists of modified layers of mucous membrane, the uterine arteries and veins opening into the sinuses. It has not been decided whether these sinneses are maternal or foetal. It is generally believed that these sinuses are filled with blood. The chorion sends its villi along with the blood vessels into the scrotina, so that these branches enter into the uterine sinuses, to be freely bathed in the blood contained within them. In this way a close connection is established between the foetus and the mother, in connection with circulation and respiration. The chief part of the placenta in the inter-villous part, which is associated with the maternal sinuses, as these are permeated by the villi from the foetus. The maternal blood is conveyed to the sinuses by the arteries, and it is carried off by the uterine veins. The foetal

blood, under the propelling force of the foetal heart, is driven along the umbilical cord in the allantois arteries, and on to the capillaries of the villi, returning by the allantois veins. There is a diffusion in connection with the maternal and foetal blood, through the delicate membrane of the capillaries, by means of their absorption, the oxygen and nutrient matters being passed from the mother to the child, and the waste matter from the child being passed through the membrane to the mother. Thus the placenta acts the part of a nutritive and excretive organ, in connection with the embryonic life, as it depends upon the maternal life.

SECTION V.—Embryonic Development and Nutrition.

We have seen that the embryo has been formed within the maternal womb, in which it is retained throughout the period of gestation. There is an intimate relation established between the mother and the child in connectiton with respiration and nutrition. These are associated with the development of the foetus, and also uterine changes in connection with the mother. It has been supposed that the uterine gland supplies nutriment for the embryo. The embryo undoubtedly absorbs nutriment from the decidua that surrounds it, but this is not sufficient to sustain its life. There is a fundamental difference between the human ovum and the egg of a fowl, based upon the amount of food that is associated with them. In connection with the egg, it is discharged entirely from the maternal body and contains within it the food that is necessary for the developing embryo. In the progress of evolution the human mother retains the embryo within the body during the period of embryonic life, giving to the embryo, as necessity requires, its nourishment. When we find the ovum in connection with the ovary, there is only sufficient nutriment associated with the deutoplasm to carry on the functions of nutrition during the early period of segmentation. Inside the Fallopian tubes there is a continuous absorption process going on in connection with the walls of the tube. When the ovum is in the uterus the segmented ovum is nourished in connenction witht the surrounding cell. This forms the basis of the theory that the uterine glands, on account of their enlargement during gestation, are engaged in furnishing nutrition to the embryo. It is more natural to suppose that the embryo absorbs nutriment in connection with the extremely vascular decidnal tissue. Even this very soon is insufficient to account for the increased growth in connection with the embryonic development; hence, to provide for this increased demand for embryonic nutrition, we find the early development of the chorion and the villi, in connection with the placenta and the vascular system of the embryo. It has been found that before the embryo is fourteen days old there is the well-marked appearance of the villi in connection with the equatorial zone. After this period in the embryonic life the chorion, as it becomes a part of the placenta, plays a very important part in the nutrition of the embryo. In this way the placenta represents the special medium, in connection with which embryonic nutrition takes place. During the development of the ovum some of the cells which originate from the primitive cell form the embryo, while others form embryonic appendages, in connection with the amnion and the chorion. The chorion is in close contact with the dicidua, and as it develops, villi branch off, these villi being embedded in the decidual surface. The chorion originally has no blood vessels, but later we find the development of the allantois, in connection with the embryonic intestinal canal. In this development we find two arteries, the

allantoic arteries, which afterward become the umbilical arteries. It is in connection with these that the blood is carried to the villi, from which it passes to the two veins, and finally to a single vein, the umbilical vein, passing along with the umbilical artery. Originally all the villi are supplied in this way with blood, but in the progress of development this blood supply is limitetd to the chorion in connection with the decidua serotina. At this part the villi become developed into large vascular masses, where the placenta is formed, the changes associated with its formation being unknown. As the placenta is formed the mucous membrane becomes hypertrophied and is absorbed, in connection with the formation of the large vascular masses of the placenta. These uterine glands give place to the blood sinuses. Even in the matured placenta there is not only a purely mechanical interchange between the maternal and the foetal blood, but also a secretory action, in connection with the epithelial cells of the villi and the decidual cells.

As the embryo demands more nutrition the decidua vera and reflexa are abolished. They are not lost, however, as in the menstrual flow, but they become gradually absorbed, in connection with the maternal body. The serotina, after having become the maternal part of the placenta, continues to bear an important relation to the embryonic nutrition during the entire intra-uterine life. At the period when the embryo ceases to depend upon the maternal nutrition the tissue becomes broken, in connection with the decidua, and the serotina is thrown off as the after-birth. In connection with the throwing off of this after-birth there is also the removal of the foetal membrane, together with the remains of the decidua vera and reflexa. In this way the entire decidua and the mucous membrane, associated with the altered uterus, is thrown off. In the embryonic development the organism demands food. So long as the alimentary canal of the embryo is in an immature condition the food must be in a digested condition, in order to be capable of rapid absorption. Oxygen must also be supplied, but not in connection with lung respiration, because the lung is in a collapsed condition. CO_2 must be eliminated, and this must take place through some other channel than the lungs. The excretory organs are as yet inactive, the kidneys and the skin not being active, either at all, or only to a very slight extent, during the foetal life. The processes of interchange require to take place, and all the interchanges, therefore, take place in connection with the placenta, the embryonic blood being brought to it, including the venous blood that has been directly circulated through the arterial system. To the placenta there is brought a mixed blood, including the venous blood, which contains the waste of the body and the blood that has been purified, in connection with its passage through the ductus venosus, inferior vena cava, the right auricle, the foramen ovale and the left side of the heart, in connection with the aorta and the umbilical arteries. From the maternal side there is brought to the placenta arterial blood, charged with oxygen and with nutriment. Thus the maternal and the foetal blood are brought together, separated by a delicate membrane, absorption taking place between the maternal and the foetal vessels. The arterialized blood is carried back to the foetal liver and heart, with its supply of nutriment and oxygen; and the waste blood of the foetus is carried back to the maternal excretory organs. In this way the placenta represents the medium of absorption between the embryonic cells and the alimentary and secretory, as well as excretory organs of the mother. In this way the alimentation of the child is carried on by the mother, absorption carrying the alimentation principles into the foetus, so as to prepare for the metabolic processes that are carried

on within the foetal body. In connection with the placental process there is not only a simple diffusion and filtration process, but in addition, a secretory process, in connection with the intervening cells. It is true that the process is largely one of absorption, but this does not exclude a true nutritive secretion in connection with the placental processes.

The embryonic heart is found to consist of a beating sinus venosus and bulbus arteriosus, both in communication with the ventricle. There is a septum in connection with the ventricle, and the sinus venosus separating both into two parts, the right auricle communicating with the left, through the foramen ovale. We next find the formation of the aorta and the pulmonary artery, with a branch between them, the ductus arteriosus. As the foetus becomes matured the fluid, which comes from the placenta through the umbilical vein, passes to the vena cava through the ductus venosus, while part of it passes through two channels that are in communication with the portal vein, passing the blood from the intestines into the liver, from which it passes to the vena cava, through the hepatic vein. When the blood has passed through the placenta and the liver, and is found in the vena cava, it is purely arterial, but very soon it is mixed with the venous blood coming back from the body, and thus ceases to be arterial before it returns to the heart. In passing to the right auricle it is mixed with the venous blood coming from the head and the upper extremities of the body through the descending vena cava, but this mixture is prevented by the Eustachian valve, which passes the arterial blood into the left heart, through the foramen ovale, at the same time passing venous blood into the right ventricle. As the ventricles contract, the arterial blood that is found in the left ventricle is thrown into the ascending aorta, and furnishes blood to the head and the upper part of the body; the venous blood of the right ventricle is then driven into the pulmonary artery, passing through the ductus arteriosus into the descending aorta, where it is mixed with the arterial blood, supplying the trunk and the lower parts of the body with a mixed blood. Part of this blood is carried back by the umbilical arteries to the placenta, where it is purified, and from which it returns in its purified condition. In connection with this foetal blood circulation the head and the upper parts of the body are furnished with pure arterial blood, as it comes direct from the placenta, while the body trunk and the lower extremity receive a mixed blood. This is said to be the reason for the increased development of the head and the upper extremities, representing an increased size. At and after birth the foetal circulation becmes considerably modified. When the lungs cease to be collapsed and become distended, in connection with respiration, part of the blood of the pulmonary artery passes into the lungs, in order to be oxygenated, and as the lungs become more active, the amount of blood that enters into the lungs increases, with the result that the ductus arteriosus ultimately disappears. Accompanying this is the closure of the foramen ovale, in connection with a valvular fold, so that the direct connection between the two auricles is removed. After these modifications have taken place we have the change in the blood circulation from that of the cold-blooded to the warm-blooded animal condition, all the venous blood which has returned to the right side of the heart passing through the lungs before returning to the left side of the heart, in order to be oxygenated and then transmitted through the arterial system. After birth, there is a disappearance of the umbilical arteries, at least in the umbilical function, part of them becoming the superior vesicle arteries and part the ligaments of the bladder. The umbilical vein is changed into the ligamentum teres.

The amount of food required by the embryo is originally very small, but it increases with the embryonic development. The same thing is true of the oxygen. Hence we find that the simple means of nourishment and respiration, found by the contact of the cells in the uterine mucous membrane, give place to the vascular arrangements of the placenta, in connection with which the embryo lives and breathes through the mother. From the earliest period of embryonic existence the placental blood circulation represents the only means of nutrition. In the early embryonic life the amount of blood found in the embryonic tissue is very small, while a large amount is found in the placenta: later the embryo takes up a larger amount of the blood, only a very small part being found in connection with the placenta. As these changes take place the cellular elements of the placenta pass through important modifications. The foetal heart begins to beat, and its rapid pulsations force the foetal blood along the umbilical artery to the chorion capillaries, being returned in connection with the umbilical vein. It is found by experiments upon some of the lower animals that there is a considerable blood pressure in the umbilical artery, and also in the umbilical vein, in the former case from forty to sixty mm. of Hg., and in the latter case from twenty to thirty mm. of Hg. This represents a greater pressure than the venous pressure in the maternal vein. Hence the difference between the arterial and venous pressure is less than in the maternal. Accompanying this the blood flow is slower. The number of red corpuscles in the foetal blood is less than in the maternal blood, although the red corpuscles are gradually becoming more numerous. It is found that between the umbilical arteries and the umbilical vein there is very little difference in the color of the blood, with this exception, that the blood of the vein is of a brighter color, usually, than that of the arteries. The blood in the vein has more oxygen and less Co_2 than that of the arteries. Hence the umbilical vein contains arterial blood and the umbilical arteries venous blood. The arterial blood in the foetus has less oxygen than that of the mother. This does not depend on the amount of haemoglobin, because there is not complete saturation of the haemoglobin with oxygen. The maternal blood passes to the placenta sinuses through arteries that open directly into the sinuses. Hence, although the blood that passes from the sinuses to the uterine veins is venous, yet the blood found in the sinuses, in connection with the villi capillaries, is arterial, rather than venous, having more oxygen and less Co_2 than the foetal blood, that reaches the placenta through the umbilical arteries. As the uterine arteries are narrow and open into the wide sinuses of the placenta, the sinus flow is slow. In the foetal blood vessels the blood flow is also slow, giving sufficient time for the interchange of gases. This interchange takes place largely, if not altogether, by diffusion, the interchange depending upon the amount of the gases found in the maternal and in the foetal blood.

The foetal breathing thus takes place through or in connection with the maternal blood. Asphyxiation of the foetus may take place in one of two ways: either by an interruption of the foetal blood flow to the placenta, as by ligature, or obstruction of the cord; or by an interruption of the maternal circulation, or by the absence of oxygen in the maternal blood. In the asphyxiation of the mother the foetus is also asphyxiated, on account of the absence of oxygen. Not only does foetal respiration take place through the placenta, but also nutrition and excretion. The blood that passes along the umbilical vein is not only laden with oxygen, but also with nutriment. The embryonic nutrition takes place under the special conditions involved in the encasement of the embryo in the

double membraneous sac of the amnion and the chorion. Between these two we find a space in connection with which the development of the allantois takes place, in connection with the formation of the placenta. With the increase in the fluid in the inner sac, without any increase in the fluid between the two sacs, the amnion becomes merged in the chorion after the placenta is developed. The entire internal surface of the uterus is lined with a membrane, which is composed of the amnion and chorion, inside of which we find the amniotic fluid. In the placental part of the uterus this amniotic fluid is brought into close connection with the foetal and maternal circulation, the maternal circuluation being separated from it only by a delicate wall and a membrane. The fluid is also in close connection with the blood vessels of the decidua, and in the later embryonic life, with the blood vessels of the mucous membrane of the uterus. This implies the possibility of transudiation from the maternal blood into the amniotic fluid of certain substances in addition to water. Hence the amniotic fluid, at least in the later stages of the foetal life, is derived from the mother, as well as the foetus. The mouth, the nasal passages and the anus of the foetus open into this amniotic space, into which there is the excretion of whatever is given off from the foetus, including the meconium from the alimentary canal. In the foetal nutrition the same substances, essentially, are utilized as those found in connection with the adult nutrition. In the passage of such substances as proteids, carbohydrates, fats and salts, we have a diffusion process, but we must also take account of the fact that the physical laws of diffusion and filtration cannot account for this process; we must take account of the vital action of the membranes. There is evidence that substances which are diffusible can pass very easily from the foetus to the mother, and vice versa, as in the case of injection of strychnine, either into the mother or into the foetus, it may produce the death of both. It is undoubted that water and certain substances in solution in the water pass from the maternal blood to the foetal blood. Yet we must take account of the fact that the specific gravity of the foetal blood is above that of the maternal blood, and that if the diffusion process alone was to be taken account of, there would be equalization of the specific gravity. The probability is that the epithelial placental cells, including the villi and decidual cells, play an important part in the process of transudation, and that this represents a secretory process.

In regard to the changes that take place in the proteids and peptones, as well as the fats and carbohydrates, there is very little evidence. It is claimed that the mother does not furnish fat to the foetus in the fat form. Glycogen has been found in connection with the placenta, and it is claimed, in connection with this and some other substances, that the placenta exercises an influence analogous to the action of the hepatic cells, in connection with the substances that are passed from the mother to the foetus. In addition to this, it is claimed that the placenta exercises a secretory, metabolic action, analogous to that performed by the mammary glands. In this way the placenta is supposed to discharge functions in connection with the foetal nutrition corresponding with the alimentary canal, the liver and the mammary glands. The embryonic tissues are found to be protoplasmic; in other words, we find differentiated elements in connection with an undifferentiated substance. This seems to indicate that a metabolic process is going on. When the differentiation becomes more complete, the foetal tissue would be capable of storing up in its tissues certain substances. Hence we find in the foetal tissues, very early in the embryonic life, a storage of glycogen, the glycogen forming a large part of the foetal substance and indicating

the organs in which differentiation takes place. During the first five months of the intra-uterine life this glycogen storage is largely found in connection with the muscles; after this the glycogen storage takes place in connection with the liver. This represents the close of what is called the period of histological differentiation; after this the glycogen is stored and utilized very much in the same way as we find it in the adult life. It is almost impossible to trace out the development of embryonic functional differentiation. On the analogy of some of the lower animals, as in the case of the chicken, muscular contractility seems to be developed very soon, and there is a heart pulsation, even before the development of the blood corpuscles. It is claimed that foetal movements are found about the end of the fourth month. Some claim that foetal movements are found before this period, but these are of a reflex character. The characteristic automatic movements are found after the sixteenth week, including the movements of the limbs, even before the brain has been developed. In regard to the digestive functions the development of the gastric actions does not seem to take place until late in the uterine life. It is claimed by some that after the fourth month there is a gastric secretion, but it cannot be proved that such a secretion truly takes place during the intra-uterine life The liver functions are found to be early developed—after the twelfth week the bile, salts and pigment being found in connection with the intestinal canal. The bile secretion is found to accumulate in the intestinal canal, together with some of the broken-up epithelial cells, passing into the rectum and forming the meconium. In the formation of bile we have the indication of the beginning of foetal metabolism, and also the excretory action of the liver, as well as of the kidney. The kidney secretion is found in connection with the amniotic fluid at an early period in the foetal development, urea being found before any foetal kidney secretion takes places, possibly being derived from maternal origin. It is certain that as early as the seventh month urine containing urea is found in the foetal bladder. We have no evidence of any sweat secretion in connection with uterine life, and if any such secretion does take place, it takes place in connection with the discharge of solid subustances. As the embryonic life approaches to its close the different kinds of blood become mixed in the right auricle, as a preparation for the after-birth changes.

During the entire embryonic life the oxygen found in the blood, as it passes to the brain, prevents any inspiration from originating in connection with the medullary respiratory center. Hence the supply of oxygen is never exhausted to such an extent as to stimulate the respiratory centers. As soon as there is an interruption of the maternal and foetal relations by the separation of the placenta or by the cutting of the umbilical cord, or by the maternal death, the umbilical blood is no longer supplied with oxygen from the maternal blood, with the result that the oxygen supply, in connection with the respiratory center, is diminished to such an extent as to generate impulses from the respiratory center, and thus stimulate the first inspiration. The stimulation of the respiratory center is assisted by impulses passing to the center from the periphery, as in connection with the exposure of the body. If respiration is retarded it may be stimulated by the dashing of cold water upon the face and the removal of the obstruction of mucus in the nasal passages. At the first inspiration, in connection witht the free entrance of air into the lungs, the lung inflation takes place, and the blood supply, which was passing from the right ventricle along the pulmonary artery, is returned to the left ventricle, more richly supplied with oxygen than during the foetal life. As the thorax is expanded, the resistance, in

connection with the pulmonary circulation, is diminished, with the result that a larger blood supply is passed into the pulmonary artery, rather than to the ductus arteriosus, so that as the continued respiratory movements take place in succession, there is the diminution, gradually, of the blood that passes along the ductus arteriosus, with the result that the channel is entirely closed. At the same time a larger amount of blood is returned from the pulmonary vein to the left auricle, the current through the ductus venosus from the umbilical vein ceasing, and the flow from the inferior vena cava being diminished; as the blood of the right auricle finds little resistance towards the ventricle which discharges its contents into the pulmonary artery, and finding, at the same time, an obstacle to its passing through the foramen ovale, it ceases to flow along that channel, with the result that the foramen ovale is also closed, and there is a complete separation of the two auricles.

SECTION VI.—Parturition.

In connection with the development of the embryo, changes take place in the body of the mother. The entire body, including all its organs, is subject to such changes, including functional changes, but it is in the uterus that the principal changes take place. It is very difficult to trace out these variations and to mark the point where the normal condition is changed into the pregnant condition. The cervix uteri becomes enlarged, the walls being hypertrophied, and secretion of the glands produces the mucus that closes the cervical passage. The other organs of reproduction are also more or less involved in a hyperaemic condition. The vaginal walls are covered with a serous secretion. The vulvar regions become swollen. Associated with these interchanges, from the eighth week onward, the mammary glands begin to develop, in connection with the secretion of milk. The mammary glands, during the pregnant condition, are found to consist of a number of acinous glands, closely connected together by connective tissue in the formation of a glandular organ. In connection with each gland we find a duct that opens into the nipple, each duct having a fusiform enlargement, representing the milk sac. After the cessation of lactation there is an increase of connective tissue, the mammary gland in children consisting of connective tissue, surrounding small gland ducts, with bulbous extremities. The nipple cuticle is very strongly pigmented, smooth muscle fibres, encircling the orifice of the ducts and passing to the top of the nipple. The milk secreted before and shortly after parturition is characterized by colostral corpuscles, consisting of large cells filled with fatty particles. The globules of the milk are formed in connection with the epithelial gland cells, the particles being driven into the gland lumen, and escaping from the cell, the cell being preserved in the formation of further secretion. Associated with the uterine changes, involving enlargement, are abdominal changes, often involving functional abdominal derangements, including the visceral and urinary organs. Other changes are also associated with these. The amount of nutrition necessary to sustain the mother and child increases the amount of work done by the alimentary system, with the result that there is an increase in the amount of blood and also the variation in its composition. According to some, in the early stages the blood seems to be watery, having fewer red blood corpuscles, with a smaller amount of hamaeglobin. In later stages the number of red corpuscles and the amount of the haemoglobin are increased. The heart action is also increased, some claiming that there is an increase in the rapidity of the heart pulsation, and that the left

ventricle becomes enlarged. The action of the liver and of the kidneys also becomes greater. Associated with these there is a nervous condition of irritability, sometimes involving mental depression and excitement.

In the human subject the period of gestation is commonly regarded as 280 days from the period of fecundation. The beginning of gestation is marked by the union of the spermatozoon and the ovum, but this is often unknown, artificial means being employed to estimate the period. Reckoning is often made from the time of the suspension of the menstruation, the calculation being made from the first day of the last menstruation. One of the most characteristic signs of pregnancy is the suspension of menstruation, and this has been regarded as the proof of the fact that ovulation and menstruation are closely connected. Some claim that the length of the period of gestation depends upon natural selection. This, however, overlooks the fact that physiological causes are to be found at the basis of parturition. Among the causes which have been associated with the termination of the period of gestation are pressure in connection with the uterine tissues, the cervical ganglia and contiguous nerves, this pressure taking place in connection with the foetus and the walls of the pelvis. Among others it is claimed that the tension of the uterine walls and the fatty degeneration of the decidua, as well as the venous nature of the foetal blood, stimulate the placenta and produce a hyperfunctional condition of irritability in connection with the nervous supply of the uterus. It is most probable that different causes act in different cases, some irritation arising in connection with the uterus. It is most generally stated that the stimulating cause of parturition is the fatty degeneration of the decidua. There is, however, also an irritation of the uterine nerves, resulting in spasmodic actions of the uterine muscle coatings. By the strong contraction of the muscle walls of the uterus the uterine orifice is opened, with the result that the embryo is thrown into the cervical canal. the vagina and the uterus forming one continuous cavity. By the rupture of the membrane there is the outflow of the amniotic fluid. The foetal expulsion takes place under the action of the contractile energy of the uterine walls, assisted by the abdominal muscles.

By parturition is meant the expulsion of the developed embryo, along with the attached membranes and the placenta, from the maternal body. It takes place by the contraction of the muscles in the upper part of the uterus and the contraction of the muscles of the abdominal wall. The lower part of the uterus, the cervix, the vagina and the vulva are largely inactive in the parturition process. During parturition there are said to be three characteristic stages representing the three labor periods. (1) During the first stage we find the distension of the os uteri. Towards the latter period of pregnancy the uterine walls are contracted rhythmically. As the first stage of parturition approaches these contractions become more frequent, more intense, and associated with pain. These contractions are limited to the upper part of the uterus and its attachments, and they are peristaltic in their nature. They are not regularly rhythmical, and if rhythmical they are irregular. During the first part of the parturition period the contraction gradually becomes more intense, the contractions lasting about one minute, followed by a pause of equal, and in some cases, greater length. Only partial relaxation takes place during the resting period, with the result that there is a tonic condition of contraction in connection with the muscles. Thus there is usually a contraction, followed by a brief pause, before another contraction takes place. Accompanying these contractions there is local uterine pain, which is gradually extended to the abdomen and the lower extremities.

These pains are due to the stimulation of the sensory nerves of the uterus, arising from some kind of pressure. As this contraction increases in intensity, one peristaltic wave after another becoming stronger, the uterus becomes narrower and elongated, with the result that the contents are pressed downwards towards the cervix, the embryonic head being preceded by a membranous portion, filled with fluid, the membrane being ruptured and the amniotic fluid escaping. (2) Following the escape of the fluid the uterine contractions generally cease for a time. After a short time they again begin with greater force, being accompanied by the contraction of the abdominal muscles. This results in the compression of the abdomen and an increase in the pressure in the uterus. Each inspiration contracts the abdominal cavity, brings pressure to bear on the abdominal organs and thus increases the uterine pressure. At this stage the contractile energy is brought to bear upon the head of the embryo, which is found in the cervical canal. By these contractions it is gradually pressed into the vagina, the rest of the body following under the action of the same contraction. The contractions increase in intensity, and at the same time there is an increase in the painful sensations, these being greatly increased when the embryo reaches the vulva. The muscles of the uterus and abdomen are normally sufficient to expel the child and to overcome the resistance presented by the walls of the passage through which the embryo is passed. The vaginal muscles are not actively engaged in the act of expulsion. (3) As the expulsion of the child takes place the placenta is separated from the uterine wall, in connection with a rupture of the tissue that is loosened after the pressure has been released, the placenta being still connected with the child by means of the umbilical cord. The muscular contractions continue until the placenta is ejected. Associated with this stage we find that there is hemorrhage, due to the injuring of the passages and the rupture of the vessels following the separation of the placental attachment; after this the uterus becomes compressed and arrests the hemorrhage.

These uterine contractions are partly reflex and partly automatic. The nerve supply of the uterus comes from the abdominal sympathetics and from the spinal cord in connection with the sacral plexus. When all nerve connection is cut off these contractions may continue, indicating that there is an automatic muscular contraction of the uterus, independent, to a large extent, of the extrinsic nervous connection. As no nerve cells are found in the uterine walls, it is claimed that in origin these contractions are muscular, being regulated and controlled by nerve impulses. The muscle of the uterus seems to be very sensitive to stimulation, even after it has been removed from the body. The entire parturition process is a reflex act, the nerve centers being found in the lumbar region of the cord. Goltz found in dogs parturition after the division of the spinal cord at the first lumbar vertebra, and it has also been found that where paraplegia existed, cord conduction being interrupted in the dorsal region, that delivery was not impossible. In a dog in which the cord was divided in the thoracic region, parturition was still possible. In connection with the administration of anasthetics it is found that the contractions associated with the uterus and the abdominal muscles must be involuntary. The sympathetic nerves are said to supply the circular coat of the uterine walls with vaso-constrictor fibres, the spinal nerves supplying the vaso-dilator fibres to the longitudinal coatings. It is found that stimulating the uterus, the vagina and the vulva, as well as the sciatic nerve, and even the mammary glands, produces contractions reflexly of the uterus. By stimulaing the medulla, the cerebellum, the pons and the corpus striatum, similar reflex contractions are found to take place. This seems to in-

dicate that parturition is a very complex reflex action, although we must not forget the automatic action of the uterine muscular fibres. In connection with experiments upon the uterus in its non-pregnant condition, it is found that it can be stimulated reflexly, in connection with the central nervous system, rhythmic contractions taking place. In the condition of pregnancy, particularly in the later stages of gestation, strong rhythmic contractions take place without any external stimulation, and are also freely called forth by afferent stimulation. The same contractions may be produced by stimulating the spinal cord at any part of its course, and also by stimulating the brain. These stimuli seem to pass down to the reflex center in the spinal cord. Uterine movements are also produced by the absence of oxygenation, in connection with the blood, as for example, in asphyxiated blood condition, when there is an expulsion of the foetus. Ergot is found, also, to produce increased uterine contractions, probably by directly affecting the center. In cases of necessity requiring the removal of the after-birth this can be accomplished by stimulating by compression the abdominal walls, or by stimulating the nipple, or by artificial irritation of the vagina. The uterine nerves pass along with the blood vessels, some being medullated and others non-medullated, passing from the pelvic plexus, in connection with which we find numerous ganglia; we also find numerous ganglia in connection with the nerves that pass to the uterus from the pelvic plexus. The pelvic plexus is found as the prolongation of the hypogastric plexus, being enlarged by nerve fibres that come directly from the sacral roots. In the dog it is found that the nerve fibres are associated with the upper lumbar, passing through the hypogastric, sympathetic and also in connection with the first and second sacral nerves. In the human subject the nerve roots are found in connection with the upper lumbar, the second, third and fourth sacral nerves. By stimulating the hypogastric nerve on the sacral nerves in the dog, uterine contractions take place; if the sacral nerves alone are stimulated, the longitudinal fibres contract, while if the hypogastric nerve is stimulated the circular fibres contract. This is said to indicate the difference in the fibres; there is also another difference, the hypogastric nerves furnishing the vaso-constrictors and the sacral nerves the vaso-dilators.

In connection with the changes that take place in the uterus and what is contained within it, there are found to be stimulations resulting in uterine contraction even before the period of parturition. Some other causes may delay these contractions beyond the normal period. There is no sufficient cause at present to be found either in observation or in experiments to furnish a basis for a theory in regard to the physiological production of parturition. All that can be said is that parturition represents a climax in a series of changes which involve the development of a new oarganism, the new organism requiring to be separated at an appropriate time from the maternal organism in order to establish its own independent existence.

In connection with parturition it is well to notice the possibility of multiple conception. Reports indicate great variation in the frequency of these multiple as compared with single conceptions. It has been found by observing the conditions of the Graafian follicles where multiple conception has taken place, that it may take place in connection with a single ovum or separate ova. In some cases there is found at the period of birth, a double chorion, while in other cases there is found only a single chorion. In the one case the two ova may arise from a single Graafian follicle, or from two follicles found in connection with one ovary or two ovaries. The two ova seem to be discharged and fecundated at about

the same time, two separate amnions being found. Two placentas are sometimes found, while in other cases only a single placenta is found. Where the two originate from a single ovum it is only possible that this could take place in connection with double nuclei in the ovum. According to Ahlfeld, the probability is that it is not due to the presence of double nuclei, but to the division of the blastomere after the first segmentation process. It has been proved in connection with some of the lower animals, that if a single blastomere is separated from the others, it is capable of being developed into a complete embryo. This would account for cases of monstrosity in which, instead of the complete separation of the blastomeres, an incomplete separation exists, so that the organism would be incomplete.

SECTION VII.—Sex Determination.

It is found that among all the civilized races of people, a larger number of males are born than females. This ratio seems to remain almost steady. The question arises: what is it that determines the sex? In the embryo there is a clear differentiation of sexuality at the end of the second month. It is impossible to determine at what period, after or before fecundation, sex determination takes place. Some theories have been formulated in regard to this subject. According to Hofacker, and Saddler, it is said that if the father is the older, the probabilities are that more males will be born than females; if the male and female parents are about the same age, the probability is that more females will be born, whereas if the female parent is the older, the probability is that more females will be born also. According to Thury, the principle is laid down, that if the ovum is fecundated shortly after its discharge, there is greater probability of the product being a female; whereas, if the fecundation takes place later, there is the greater probability of male offspring. In line with this idea, it is claimed that conception shortly after menstruation results in the birth of a greater number of the female sex. Dusing, on the basis of the Thury theory, claims that if the spermatozoa are fresh, from the standpoint of their production, there is a greater probability of the product being of the male sex. He claims that in the case of animals, the fact there is a more frequent exercise of the reproductive function on account of the fewer males that are utilized, causes the increase of the male sex because the germ cells are newer. The idea of sex being determined by nutrition was formulated by Yung in 1881, who fed tadpoles with very nutritious food, the result being that there was a large increase in the female sex. The same idea has been propounded by Treat, who claims that in the case of well-nourished caterpillars, the butterfly products are female, whereas, in the case of starved caterpillars, the male product predominates. It is claimed, on the basis of statistics, that the ratio of male and female is in inverse proportion to the parental nutrition. It is claimed that more males are born in the country districts than in the cities; and also among the poorer classes of the people, that more males are born. It is also stated that as the races become intermingled, there is an increase in the number of females, whereas, in cases where the races are maintained in their purity, the males seem to predominate. Many other ideas have been brought forward, as suggestive of the solution of this question. The only principle that seems to have any foundation is that depending upon nutritive conditions: where the conditions are favorable, females are produced, and where the conditions are unfavorable, males are produced.

One important modern theory deserves more than a mere passing notice. Schenk has formulated a theory in regard to the influences that bear upon sex production. According to this theory it is claimed that sex production can be controlled from the standpoint of nutrition. If this is correct, then the trophic influences have an important bearing not only upon the variations in the individual life, but also upon the transmissibility of the hereditary properties of life. In his work on the "Determination of Sex," he has reviewed historically all the theories that have been formulated on this subject, presenting his own conclusions, and also the experimental view based upon his own observations. His chief aim is to remove all sugar from the excretions of the maternal body. His theory is, that where traces of sugar are found in the mother during the child-bearing, the result, so far as the ovum is concerned, is the development of a less perfect organism, there being an imperfect body activity, resulting in the female child. In order to accomplish this, a diet of proteid material is to be used, nearly all of the carbohydrate being eliminated from the food. This dieting, according to Schenk, must be commenced several months before conception, and continued for several months after. He admits that he cannot yet entirely control sex production, but claims to have established his theory to the extent of assisting in the maternal selection of sex. His chief work has been to examine the excretions of the body with the view of discovering the presence of carbohydrates. He claims that the presence of sugar in these excretions indicates imperfections of some kind, in body development. In the case of the female body, he claims that there is a smaller change than in the male body, this being due to less active changes in the blood, and also in the alimentary processes. Where the sugar, taken in the form of food, is eliminated as waste, there is an indication of imperfect action of the body mechanism, exhibiting less oxidation power in the process of combustion. Where the activity of the body is less, there are less active changes, and the result is a lesser degree of strength. For this reason men are physically stronger than women. Hence, where there is imperfect action of the digestive mechanism, it is more noticeable in the female, because of the lesser degree of strength. It is of the greatest importance therefore, that during the process of child-bearing, the female strength should be most perfect, representing the most perfect conditions of the body mechanism. Hence, if the body is imperfectly nourished, and incapable of performing perfectly digestive functions, there is a decided influence upon the ovum. Where the carbohydrates are absent, the female organism is stronger, and can produce as well as sustain, a stronger and more perfect child. Where the organism is imperfect, the ovum is also imperfectly developed. In the former case, Schenk thinks there is developed a male child, and in the latter, a female child.

Primarily, the germ plasm does not possess sex characteristics; the sex characteristics depending on the environment, chiefly nutrition, the more fully developed and nourished becoming the male, and the less fully developed and nourished, the female. In order to control the sex and produce the male, Schenk says that the diet must be so regulated as to eliminate every trace of sugar from the waste. This dieting must depend upon the individual case, as Schenk admits that in some cases where the dieting is purely proteid, a larger proportion of saccharine was found than in the case of dieting on fats and carbohydrates. The normal dieting is the nitrogenous food with fats, and only so much carbohydrate food as is necessary to keep up the body activity without danger of loss to the system. He claims that only one theory is tenable in connection with the many theories that have been formulated, namely, the theory of

cross-heredity of sex. In order to establish this theory, he set himself to examine the excreted products, examining more particularly the carbohydrates as they are excreted from the urine. Carbohydrate excretion in the urine means that the combustion process is incomplete, the organism being so impaired as to interfere with the use of combustible substances. When sugar is found in the urine, he claims that it ought not to have been secreted, as grape sugar. If the organism is in perfect efficiency, grape sugar could not be secreted unchanged, but would be oxidized. This does not mean that the organism is in a pathological condition, as he claims that in cases in which the sugar has been found, no pathological condition could be detected. The presence of sugar therefore, in connection with the urine, may indicate a physiological condition. Even if the sugar is excreted for a long time, it does not of necessity indicate a pathological process. On the other hand, where no sugar or only a very small quantity of sugar can be discovered in the urine, there is the indication of perfect capacity to use all the carbohydrates in connection with the metabolic process. If this condition is not found to a certain degree in an individual, then to that degree there is the failure to perform the full physiological functions of the individual. Ivanoff says that a physiological condition of glycosuria in the case of pregnant women has never yet been established, sugar not being found in constant and increased quantities in pregnant women. In the female organism there is found to be a less abundant tissue formation than in the male, and yet according to Schenk, there is about the same amount of sugar given off in the urine. Where the formation of tissue is less abundant the strength must be weaker, hence the weakness in the organism will influence more completely the organism itself and the functions that it performs.

Hence the excretion of sugar in the female indicates a greater loss than in the male.

In addition to this fact, there takes place periodically menstruation and ovulation in the female, so that it is of importance to find out whether there is a complete use made of the substance that is taken as nutrition. Hence the question of the excretion of sugar has an important bearing on the formation of the ovum and its maturation. Sugar is excreted not only on account of the nature of the food, but especially in connection with the oxidation processes. It is essential in the maturation of the ovum that metabolism should be normal, and if these processes are normal, sugar will not be present in the urine. Ovum formation does not depend entirely upon food and metabolism. Where it is found that substances are not completely oxidized, there is the incomplete development of the ovum. In this case there will be "a less perfect ovum, and also a less well-nourished ovum. An ovum of this sort has not so fully attained to all the characteristics and powers inherent in its protoplasm, and in consequence seems fitted to develop only a female individual. In such an ovum the several cell products of the ovum which have to develop themselves into the future embryo will be arranged for the growth of a female. Not only will female organs of generation be developed from it, but also all the elements of the future individual may be feminine." On the other hand, if in the maternal organism all the substances taken in the form of food or developed in the organisms are completely oxidized, so that not even the smallest traces of sugar are found in the urine, "then an ovum can be developed such as is required to produce a male individual. Out of this protoplasm, in the course of evolution, elements form themselves whence male cells are developed, which correspond to the development of tissues and forms of the male individual. Some of the cells—namely,

those which ultimately become the elements for the continuation of the species—are planned for the male sex." Hence he concludes that the determination of sex depends upon a fitting diet and its choice to suit the organism, so that the diet may exert such an influence over the maturation process as to develop the male germ. This principle can only be applied in the ovum development before fecundation. The chief requisite is that the maternal parent has been for a considerable time prior to fecundation carefully dieted. At the same time, special care is required after conception that the diet may also be fitting. This theory is in too formative a stage to be discussed. One objectionable feature in the theory is its seeming depreciation of the female sex. Even if the sex can be controlled by nutritional changes, and such is possible on the basis of environmental changes, it would seem that nothing can be drawn from this that would in any sense lead us to appreciate one sex above another. It has been generally admitted that in the body germ-plasm stage there is no sex differentiation, this taking place in the later embryonic stages. If by a regulated dieting this differentiation can be guided, it furnishes a proof of the influence of environment upon the development of the germ plasm. This theory may be criticised from a preformative standpoint according to which every germ plasm represents a complete and perfect organism with all its parts and powers latent, so that no power can change its sex. If the preformative theory is true, then a sexless germ is an impossibility, for the germ plasm must contain all the potentialities of life in a perfect condition. From this standpoint the only possible way of controlling sex would be to prevent inception.

Another theory has been formulated, based upon the fact that when men are in a low vital condition from diseases or old age, they usually bear sons. Thus, it is claimed, represents the effort of nature to strengthen the weaker sex with the view of reintegrating lessened vitality. This theory was found to be the reverse in the female sex. Hence Shepherd formulated what he called the polarity theory. According to this theory, the germ comes to exist as a perfectly complete organism, in connection with which latent potentialities are developed by the law of polarity and under the influence of environment. Hence, when the germ is found in the maternal soil it is impossible to alter sexuality. According to this theory the universe consists of matter and electricity—electricity representing life, or rather, life being the union of electricity and matter. The beginning of each separate life represents a minute life-generated spark emanating from the infinite potentiality. Electricity is positive and negative, the former representing the male from which is generated the spark of life. According to this theory the male and female germs represent opposite polarizations—the former representing the energetic element, and the latter that in connection with which the energy is developed. According to this the germ life begins with inception, and from that moment the struggle for existence is commenced. Environment also has an influence, for if germs of the male and female are placed in a negative soil, the male germ will survive as against the female; whereas if the male and female germs are placed in a maternal soil of luxuriance, the female germs will survive. This theory has in it the idea of vital magnetism or magnetic electricity, and in order to its acceptance it is necessary to accept of life, including vital and nervous activities, as being essentially electrical or electro-magnetic.

CHAPTER XIV.

Physiological Conditions Peculiar to Age, Temperament, Changes of Life, and Death.

SECTION I.—*The Phases of Individual Life.*

The individual life begins with fecundation and ends with the death of the body. During the intervening period between these two events there are characteristic changes which are peculiar to the different phases of life—these changes representing sometimes sudden variations. We find such periods as the foetal period, childhood, youth, maturity and old age. There is not, however, physiologically, any hard-and-fast line of separation marking off these stages from one another, and hence the periods are simply relative. Before birth the structure is completed, and the functional arrangements of the body mechanism develop. At birth the independent existence begins, when all the functions of normal life except reproduction are more or less developed. From birth to maturity these functions are modified, the modifications taking place as essential enlargements of the primary functions. The growth of the body consists of enlargement of the cells, the multiplication of the cells and the development of the connective tissue substance. During the embryonic stage the cell multiplication takes place; after birth the enlargement of existing cells takes place, together with the growth of the inter-cellular substance between the cells. Resulting from the cell growth there is an increase in the body size. The body growth goes on continuously from the beginning of ovum segmentation till about twenty-five years of age. The variations in the size of the body depend to a large extent upon a number of conditions, depending upon climate, food, etc.

In connection with the body-growth after birth, two methods have been followed, the one depending upon the average found in connection with development of a number of individuals. In the other case, measurements are taken at different periods in the same individual life, indicating that the individual himself is increasing in a definite or determined ratio. It is found that growth is rapid during the first five or six years of life, becoming slower from the fifth to the tenth or twelfth years. Between the twelfth and sixteenth or seventeenth years there is found to be another development, after which the first growth becomes slow until the twenty-first or twenty-fifth year. During the next five or ten years the body weight is generally increased, although there is but very little variation in the body height. In connection with the relative development of the male and female, it is found that males grow more rapidly than females: in the development of the years from ten to twelve up to puberty, it is found that there is an increase in the female growth as compared with the male growth. About fifteen years of age it is found that the males grow more quickly than the females—the males attaining their adult stature from twenty-two or twenty-five, and the female from twenty to twenty-one years of age. Alterations may take place in connection with climate and the conditions of life, but the results seem to depend largely upon the differences found in the sexes themselves. When the child is born it represents a very incomplete development. The newly-born child weighs about seven pounds. The body is pretty nearly divided in two

at the umbilicus, the head and the upper extremities being larger proportionately than the pelvic region and the lower extremities. In addition to this the thorax is small and the abdomen large. There is a partial curvature of the lower limbs, so that the feet are oblique rather than horizontal—the limbs and the arms being bent forward in connection with the thorax and the abdomen, the joints also being in a partially bent condition. The respiratory process is imperfect for a considerable period after birth, the pulmonary vessels expanding gradually, and the circulatory modifications taking place also gradually.

The early respiration of the new-born child seems to take place to a considerable extent in connection with the skin. The body temperature is low and requires to be sustained by careful protection. Sleep seems to be almost the normal condition, the special senses remaining almost unexcited and consciousness being almost entirely absent. The voluntary motions and sensations have not been developed, and the movements that are found associated with the limbs are automatic in their nature. All or nearly all the actions of the infant are reflex in their character—as for example, suckling. The nervous connection with the external world is incomplete, nutrition and respiration representing the two main functions of the body organism. As the development of the body goes on from infancy there is a diminution in the relative size of the internal organs, on account of the increased growth of the bony and muscular systems, both of which come to be developed very fully in connection with the structural and functional growth of the body. The umbilical cord very soon becomes desiccated. The skin is renewed over the entire body, this including the hair that is found on the different parts of the body. The teeth are only partially developed, being still concealed in the dental follicles. At the period of birth there is a delicate layer covering over the upper surfaces, only afterwards the body and the fangs of the teeth being formed. The teeth pass out of the gums, according to Kolliker, in this order generally: the central incisors about the seventh month after birth, the lateral incisors about the eighth month, the anterior molars about the end of twelve months, the canines about the end of eighteen months, and the second molars about the end of twenty-four months. About the seventh year another change takes place, in connection with the replacing of the first teeth by the permanent teeth. The anterior permanent molars are first seen close behind the posterior temporary molars. About the seventh year there is the casting of the middle incisors, which are replaced by larger teeth. In the eighth year the lateral incisors are thrown off and permanent teeth take their place. About the tenth year the permanent bicuspid teeth replace the anterior and second molars. During the twelfth year we find the throwing off of the canine teeth. During the thirteenth year the permanent molars appear, and from the sixteenth to the twenty-second year the wisdom teeth are found in connection with the dental arch.

The generative organs, which do not exist at birth, begin to show functional developmen from the fourteenth to the twenty-first year. At this stage the general body form is altered, and there is a difference between the sexes. At this period we have the changes that are associated with puberty, puberty indicating the period when sexual maturity is reached. It is said to be later in the male by one or two years than in the female. Accompanying this change there is a rapid increase in the body growth. In the male it is accompanied by marked alteration in the body size, development of strength, maturity of function, especially of the reproductive organs—one of the most marked changes being that of the voice, which falls permanently about an octave. In the female the

approach of puberty is more readily determined than in the male. It is marked by characteristic body changes, one of the most marked being associated with menstruation and the uterine changes accompanying it. Nervous changes and also mental development are found characteristic of this period of puberty. After a certain period of life is reached in the male, usually about sixty years, the life begins to decline, this being manifest in connection with the diminution of the reproductive powers. It is not so marked in the male as in the female, the reproductive power ceasing about forty-five to forty-seven years of age in the female, this period of life representing what is called the climacteric. It is chiefly characterized by the cessation of the menstrual flow, accompanied by changes in the entire reproductive organs, including the mammae, which decrease in size. The changes that take place in connection with the pelvic organs are the reverse of those that are found to take place at puberty. There is involved in most cases an abnormal condition of many of the body functions, including digestion, blood circulation, heart action, etc. In many cases there is found a profound change in the system, involving rheumatic and neuralgic conditions, as well as a tendency to hysteria, and sometimes to mental disorders. There is involved in these changes a modification of the reproductive functions, and with this modification a new adaptation of the body system to these changed conditions. In connection with the variations that are found in connection with the child life, it is found that the brain and the eyes are relatively larger in comparison with the body weight. The same thing is true of the skin, as the small body has a relatively greater surface. In connection with the kidneys we find a larger development in the embryonic life, while in regard to the heart and liver we find the same relative largeness. The lungs and the alimentary organs seem to have about the same proportion to the body as in the adult life. The same thing is true of the skeleton, while the muscles develop much more quickly than the other parts of the body. In the child it is found that salivation is almost entirely absent, the teething process representing the beginning of the active development of the saliva. The gastric juice in the infant, as well as the pancreatic juice, has considerable digestive capacity. This seems to indicate that the digestive processes in the child are very similar relatively to those found in the adult, with the exception that starch or starchy food is very difficult of digestion. It has been remarked that in the infant faeces there is a large amount of undigested food, indicating the limited extent to which the digestive process can be carried in the child. The heart in the case of the child is much larger than in the adult, relatively to the body weight. The heart pulsation is also very much quicker—at birth being about 40 per minute, in the second year being about 110, and about the ninth or tenth year falling to 90. The blood circulation takes place in a very much shorter time—in about twelve or thirteen seconds, as compared with twenty-three to twenty-five seconds in the adult. This provides for the very rapid renewal of the blood in connection with its circulation. We find also a larger amount of blood relatively to size in the infant than in the adult. Child respiration is much quicker—at birth being about 36 per minute, in the second year about 28, and gradually decreasing year by year until it assumes the normal. The oxygen absorption is found to be in the child life very active, being much greater than the elimination of carbonic acid—indicating that there is a storage of oxygen in order to provide for the very rapid and at the same time large constructive metabolism. In connection with the food that is taken into the body, there is required a large amount of energy in the conversion of the food substance into body tissue. The metabolic processes of

the child are very much more definite than those of the adult, on account of the increasing development of the body tissue. In addition to the larger amount of tissue that is required, a more rapid metabolism is necessary to sustain the body temperature, which normally is above that of the adult. In the child we find a relatively larger surface, so that the loss of heat is greater, and greater precautions require to be taken in preserving the child from cold.

Closely connected with the growth of tissue, and the metabolic and digestive processes which are at the basis of this growth, is the importance attached to the lymphatic system. There is not only a large lymphatic system, but also a large quantity of lymph. There is also a special fluid gland, the thymus, which grows quickly up to the second or third year, and then remains in about the same condition for several years until it gradually disappears. Thyroid development and spleen activity are greater in the child, on account of the necessity of the child's system demanding the increase in the blood corpuscles, and also in the thyroid secretion. In the child life the urine is found to be more abundant than in the adult life. This is claimed to be due in part to the liquid nature of the food, but it also depends upon the increased metabolism that is associated with the infant growth. There is a larger amount of urea and other solid substances —uric acid being found in large quantities in the urine of children. In connection with the nervous system, it is found that in childhood there is a greater degree of excitability, indicating that the nervous mechanism has not been developed, but is being subjected to a great number of stimuli which are constantly producing modifications in the nervous system. The development of medullation takes place gradually in connection with the nerve fibres, indicating that functional activity is developed later in connection with the completed nerve fibre and nerve tract. It has been found that the stimulation of the pneumogastric does not produce the inhibition of the heart, indicating that the normal function of the nerves is not performed from earliest childhood. At birth the tactile sense, both in connection with temperature and pressure, seems to be very fully developed, and also the sensations of smell and taste. The eye seems to be very sensitive to the normal stimulation of light, while the auditory sensations are not very fully developed. This latter phenomenon is explained by the fact that the moistened condition of the tympanic membrane and the absence of air do not give the necessary sensations in connection with stimulation. The nervous system becomes more settled, an excited condition giving place to a calmer nervous condition, the senses becoming more sensitive and acute. These changes represent, from the standpoint of physiology, some of the modifications that take place in connection with the changing variations of life, especially those of childhood, which are most profound.

SECTION II.—Evolution in Connection with Reproduction.

From the standpoint of biology, there are two important elements that determine and explain the character and activity of the living being, heredity and environment. Of these two the most important is heredity. Environment represents the changeable element that surrounds the individual life, including those elements of life which are considered essential to the physical and psychic existence. By heredity is meant whatever may be transmitted from ancestor to offspring, whether actual or potential. In environment is included the material, such as food, air, the water and the natural forces which act as stimuli or constitute the environing conditions of active life. Not only do these principles apply

to the origin of the organism as a whole, but also to the different cells of the organism, although there is a complication in this case arising from the influences of cell upon cell. The action in heredity is internal, and of environment external. In the unicellar organisms there is the beginning of independent existence when the parent cell is separated from the child cell, so as to form an independent body. In the higher forms of life this implies the conjunction of the spermatozoon and the ovum, when there takes place the constitution of the germ of a separate life. This forms the period of the inception of the new form of life, and from this period until death we find life consisting of the manifestations of certain capacities and powers first imparted to germ life, to which must be added the influence arising from environment.

Biology has been endeavoring to lay emphasis upon these as the two great elements in life, and from this standpoint they form the essential basis of all vital actions. From the standpoint of physiology both of these are important, not only because they are at the basis of biology, but because they are at the basis of functionalization. Already we have considered very fully the environmental element, because the entire connection of life and action, alimentation and nervous impulses originating and carrying on the life actions, whether internal or external, represent the environments of life. Their presence and influence absolutely control the manifestations of the vital phenomena. The physiological account of these living phenomena as processes of the functional life would be incomplete without taking into account the second element of heredity; particularly because around this evolution idea all modern biological investigation circles. It is true that here we meet largely with theory and opinion rather than fact, but there is a constantly accumulating mass of evidence that seems to render at least possible the theory of heredity.

In biological terms, every vital phenomenon must depend upon one of two things—either heredity or environment—or upon both of these factors. One thing is self-evident: there is no spontaneous generation, there is no self-originating power. Hence life and its phenomena are derivative. One of the most important evidences is that of resemblance. Histologically, and even from the standpoint of physiology and physiognomy, there is a resemblance between the child and the parent, including the ancestors of several generations. These resemblances appear strongest in the direct line of child from parent, back along the line of ancestry. Francis Galton, in his work on "Natural Inheritance," has differentiated the proportion of inherited resemblances—the two direct parents contributing one-fourth each, and the four grandparents one-sixteenth each, the other one-fourth being inherited from older ancestors. This theory has been denied by other investigators. It has been pointed out that in addition to individual eccentricities, including the physiognomy, there have been handed down from the ancestral line peculiar characteristics of race, so that whatever species may mean absolutely, there is a distinctly marked division of the species in the same genus.

Many theories have been formulated in connection with hereditary transmission, the oldest being that the soul of some predecessor passed into the body and made the body its residence. This represents the doctrine of transmigration, which we find in a remote antiquity, and also at the present day among savage and uncivilized races. According to Stahl, the soul represented the forming power in connection with the development of the foetus. According to Darwin, there are in existence in connection with all cell forms minute corpuscles, which are found to circulate freely in the body. These minute corpuscles are handed

down from parent to child, although they may lie latent for some time and be brought into prominence in connection with their union with other corpuscles furnished by another organism. According to Haeckel, transmission takes place not by means of substance, but through molecular movement, retention taking place by means of an unconscious memory. According to this theory, heredity would depend upon the transmissibility of molecular movements. According to Naegeli both of these theories are false. He claims that in all protoplasm we find a fluid and a solid part, the latter consisting of solid matter essential for nutrition. The idioplasm, as it is distributed throughout the body, represents the center of all the active changes—the idioplasm differing in different parts of the body. The germ cells are found to contain this idioplasm, which has been reduced in connection with the germinal process. The characteristic properties of this idioplasm depend upon the combination of very minute particles called micellae. In the case of parental transmission, if each parent transmits an equal part of idioplasm, each parent will be equally represented in the child's peculiarities; whereas, variation in the amount of the idioplasm derived from the parents will give corresponding variations in the child. The germ cell represents a cell containing the idioplasm, this idioplasm being modified to a certain extent by external conditions, so that there is not absolute resemblance between the child and the parent or parents. This theory seems to be founded upon the existence of a universal protoplasm, and is based upon an ideal conception of the idioplasm.

This theory has been modified by Strasburger. He regards protoplasm as consisting of two parts, the one formative and the other nutritive—the formative being identified with the chromatic nucleus. In connection with the nucleus he found an active substance which he called the nucleoplasm—all the variations in the cell substance taking place in connection with the nucleoplasm. According to this theory, a cell possesses reproductive power in connection with its embryonic condition. This view is claimed to explain the phenomena that are associated with the throwing off of the polar bodies from the ovum and the spermatozoon, as these cells return to their primitive condition. According to this theory, the throwing off of the polar bodies is to prevent parthenogenesis: that is, to remove from the ovum the male idioplasm, and to remove from the spermatozoon the female idioplasm, so that the truly male and female elements may be united together in fecundation. In this way the female idioplasm would transmit maternal characteristics and the male idioplasm paternal characteristics. This is the idea of Balfour, expressed in his work on embryology.

Strasburger claims, however, that the mother transmits not only maternal characteristics, but also latent characteristics of the maternal grand and great-grandfather; while the father transmits, in addition to paternal characteristics, those of the paternal grand and great-grandmother. Hence the maternal idioplasm and the paternal idioplasm do not represent purely male and female elements. According to Strasburger, the nucleoplasm consists of a number of segments representing different generations. The important point in this theory is the identification of the idioplasm with the chromatic substance. According to Beneden, if the chromatic substance from the male and from the female are kept separated, and transmitted in equal portions to the nuclei found in connection with the separation of the fecundated nucleus, and if this is continued indefinitely, each cell may be regarded as representing both father and mother, according to the extent of the maternal and paternal idioplasm. On the basis of nutritive action the idioplasm may be increased, and it may also be modified by environment giving rise to individual characteristics. As soon as the cells

cease to be increased by division, there is fixed the individual characteristic of the idioplasm. According to some, this represents the advantage associated with sexual difference, and the disadvantage that is found in the sexual union of individuals that are too closely related to one another. According to this view, the throwing off of the polar bodies is for the purpose of securing the embryonic condition, the reproductive substance being secured by transforming somatic idioplasm into embryonic or reproductive idioplasm. This involves a considerable difficulty in connection with the process of conversion of somatic into idioplasmic embryo.

This led Weissmann to formulate his theory of the continuity of the germ plasm. According to this view heredity consists, not in the transmission of idioplasm, but of a special substance associated with the germinal cells. This represents a special nuclear substance which he calls the germ-plasm, that is transmitted unaltered from generation to generation, representing a continuous and immortal germ-plasm. If it is not used up in the development of offspring, a part of it is put aside for the formation of the germ-plasm in future generations. This theory, although it seems to get over some of the difficulties involved in preceding theories, does not explain the fact of hereditary transmission. The nuclear matter associated with the molecular mechanism cannot itself be explained. If there is no possibility of altering the germ-plasm, how are we to account for individual characteristics? Weissmann denies the transmissibility of acquired characteristics, claiming that only the inherent characteristics are transmitted. All characteristics, however, must have been acquired at some period; and if this is true the germ-plasm must be subject to certain variations. These theories seem to overlook the fact that modifications take place in connection with the process of germination while the embryo is in the maternal uterus. During this embryonic condition there is undoubtedly a modification taking place through or in connection with the maternal life—the child in utero being to a certain extent influenced by all of the important changes that take place in the mother.

The human race is one, but this unity is differentiated in groups, such as the Caucasians. These hereditary resemblances may be anatomical, physiological or psychological, or all of these combined. Anatomical resemblances are the most commonly recognized—facial features, color of the hair, and of the eyes, and the form of the body, and abnormalities, such as monstrosities, vision defects. Physiological similarities include peculiar kinds of locomotive action, characteristic gait, longevity, stoutness, thinness, and abnormalities, such as consumptive tendencies. Physiological similarities depend upon habit, mental characteristics, genius, aesthetic and moral qualities, and abnormalities such as a tendency to crime, insanity. In connection with the transmission of hereditary tendencies, it is to be noted that the fact that they do not appear in the individual life does not prove that they are not inherited. It is possible that these characteristics may exist in latency, so that they may be transferred from one generation to the second succeeding generation without any manifestation in the intermediate generation. Darwin classes the peculiar latency of sex as one of the essential characteristics of heredity. He says that "in every female all the secondary male characteristics, and in every male all the secondary female characteristics, apparently exist in a latent state, ready to be evolved under certain conditions." According to this a female may inherit the secondary characteristics from her paternal grandmother that have remained latent in her father, and similarly a male may inherit secondary characteristics of the maternal

grandfather that have been in latency in the mother for a time. From a pathological standpoint it is said that hydrocele, peculiarly a male disease, may be inherited in the male from the maternal grandfather, though it is evident that it must have existed in latency. In such cases the latency involves potential activity, with capacity for manifestation where suitable organisms or environments are found.

On this principle we find the individual characteristics reappearing after the lapse of some generations, not manifested in the immediate ancestors. This subject has given rise to some of the most important researches in the field of comparative biology. Darwin, for example, regards the half-caste progeny as reversions toward primitive savagery, characteristic of the primitive ancestry of the uncivilized races, the primitive condition remaining in a state of latency. The tendency to revert to these original characteristics is more common before reaching the adult condition of life—when adult life is reached, the tendency being largely overcome by the influence of environments. In connection with heredity we must take account of the fact that there is a possible regeneration of lost parts. Physiologically this is taking place in the body all the time—the wasting and degeneration of parts giving place continually to regeneration of parts in the renewal of the organism. It is however, from a pathological standpoint that regeneration is most interesting on the heredity principle. The capacity of regeneration is subject to limitation among the human subjects; but there is a large field in which it takes place: the re-growth of the epithelial covering of a surface, the regeneration of a divided nerve, the union of severed bones, the growth of degenerated muscle, and the development of the connective tissue, furnish examples in the case of man. This regenerative power is much stronger in the lower forms of life, as in the case of the common earth-worm, which when cut in two may regenerate from a single half. There seems to be possessed by the existing portions of an organism, if these parts are not differentiated too much, the power of regenerating the lost portions, this power representing a second embryonic development in many cases.

Much discussion has taken place as to the possibility of transmitting acquired characteristics that have been developed in the parent life prior to the independent existence of the offspring. This is possible in the unicellar organisms, unquestionably, for in this case the cellular substance simply divides the offspring, taking the part of the substance as the basis of its independent life. In the case of multicellar organisms it is different—the transmission taking place in this case not in connection with the protoplasm, but through germ cells. Here the question arises as to the relation between the germ-plasm and the somatoplasm. Are the changes of the body plasm of such a kind as to involve similar or analogous changes in the germ cells developed from the body plasm? Weissmann has classified such changes under three different heads: those representing lesions, those representing functional change, and those depending on the environments. Upon the solution of this problem depend very large issues in the individual and social life. As yet there is no proof that such characteristic changes do pass by inheritance, although there is much evidence that points in this direction. It is claimed by some that aesthetic tendencies, genius, ambition, represent some of these characteristic features transmitted from parent to child. Experiments conducted by Weissmann—for example, cutting off the tails of mice for five successive generations—do not change the characteristics of these animals. The forcible compression of the Chinese girl's feet does not render unnecessary the process in every new generation. Brown-Sequard artificially

caused epilepsy in the case of guinea pigs by operations in connection with the nervous system, the same tendency being transmitted to the offspring. But this falls short of proving transmission of defects, because the system was weakened, and it resulted simply in the production of the weakened physical system. In this connection much discussion has arisen as to the possibility of transmitting diseased conditions. Diseased body plasm in the parent may produce weakened germ cells which constitutionally represent predisposition to disease, and later may develop these ancestral diseases—disease actually attacking the offspring body. Immunity to disease, as well as tendencies to certain diseases, may also be transmitted. Much experimentation has taken place in regard to the transmissibility of infection, the result being that infection seems to adhere to families for generations, although here it is probable that the predisposition is what is transmitted. In recent cases it is claimed that the micro-organism producing the diseased condition is actually communicated.

Of this kind we have two classes:

1. The germinal, in which the micro-organism is transmitted in the inception of the germ life.

2. Placental, in which by means of the blood infective germs are transmitted through the circulation. Germinal transmission has been decided by most pathologists, at least in the case of tuberculosis. It is admitted, however, that the micro-organisms can be communicated by the circulation in the intrauterine life. Many theories have been put forward to account for and explain the principle of heredity. The modern theories all date from the time when Spencer first published his Biological Principles. The basis of all theories of heredity is found in the germ plasm. The parent plasm contributes to the new life in the spermatozoon and the ovum, these representing the characteristic qualities of the parent plasm. According to the commonly accepted theory, the nuclei of the spermatozoa and the ova represent the germ life, the body of the ova and the tail of the spermatozoa representing the trophic substance and the active locomotive power respectively of the germ plasm. Hence the essential part of this germ plasm is the nuclei—the transmission taking place in connection with the characteristics of these nuclei.

There are two theories in regard to the origin of the germinal substance: The Spencerian theory that there are formed in the reproductive organs physiological units, the germ plasm representing all the different parts of the body, so that the germ cell represents a minature body organism with all the essential characteristics of the organism as a whole and in its different parts. The theory of Weissmann repudiates the Spencerian theory that the germ plasm is from all parts of the body, and says that this germ plasm originates from the parental germ plasm—this germ plasm being traceable back from generation to generation till we come to the original unicellar organism out of which are developed all of the germ plasms. Thus the germ plasm represents the primitive germ of life transmitted from generation to generation, the body organs being derived from it, but these body organisms not contributing to its continuance.

As to the nature of the germ plasm we find two theories also. Weissmann believes that structurally it is a complex body—the ovum when fertilized containing within it in germ the future embryonic cells, tissues, etc., the development of which represents the growth of the body from these original cell elements. In this way the ovum consists of various parts; these parts are segments, representing by segments the different parts of the future organism. According to the other theory the fecundated ovum, although consisting of parts, has no

essential differentiation of segments, so that the development from these simple parts is largely if not altogether a development under the influence of external influences. According to the experiments of Hertwig and others, the separate ovum segments may be developed into a normal but considerably dwarfed organism. According to this theory the ovum segmentation is quantitative, not qualitative as Weissmann claims. According to these two theories, in one case there is an organic structure from the first inception, whereas in the other case there is no organic structure, the development taking place according to circumstances. These represent the two theories of modern times. In the former case inheritance of resemblance is explained by the fact that the germ plasm is the same in the line of descent; in the latter case it is explained by the modification of the germ plasm under the influence of environment. It is claimed that resemblance is relative, never absolute, there being always a variation in the offspring from the parent. This resemblance may be germinal in its variation, originating in the germ plasm; or it may be an acquisition after inception, the result of environmental influences. Hence we have germinal resemblance, and also germinal variation in resemblance. These germinal variations depend upon the variation in the trophic condition of the germ plasm, the trophic condition being different in different germs. There is always a variation depending upon sexual conditions. The inception of the germ plasm depends upon the conjunction of two individuals, so that variations are represented in the individuals, as these in turn represent different ancestral lines, and they produce modification in the germ plasm.

Several theories have tried to explain the principle of heredity. The first place is due to the theory of Darwin, based upon pangenesis, or the theory of the generation of all living forms from a primordial living matter. Darwin began by stating that the cells of the body increase by cell division, these cells representing after development the different body tissues and organs. In addition to this he presupposed the separation from its cells of minute granules which are distributed over the whole body, these being nourished, developed and again divided, finally forming cell units similar to the original cell units. These minute granules he called gemmules. Separated as they are from all parts of the body, they are collected in the sexual organs, these minute gemmules having a natural affinity for each other, so that as they are separated from the different body units they are collected together to form sexual elements. Hence the reproductive organs are simply glands for the collecting of these organic elements from the different parts of the body—these when collected together forming the basis of the transmission of the body characteristics to future generations. Darwin explains the regeneration of lost parts of the body on his theory by the fact that when the gemmules of this lost part are scattered through the body they unite with the dormant cells at the point of regeneration. These gemmules may remain latent from one generation to another, awakening in the future generation by reversion. By the combination of the paternal and maternal gemmules it accounts for germinal variations; and also the accumulation of gemmules in connection with these acquired variations being a basis for the transmission of acquisitions.

The second place is due to the theory of August Weissmann. According to him, the germ plasm is identified with the characteristic substance of the nucleus of the germ cells. The keynote of his theory is "the continuity of germ plasm," according to which a germ-plasm of an individual originates from a germ plasm of a parent, the origin being traced backward in direct line of origin

of sex. The germ plasm is distinct from the body plasm, which represents the entire body organism except the germ. The germ continues the same from one generation to another, whereas the body plasm varies in the individual, being developed from the germ plasm. Thus the body plasm lives and dies, whereas the germ plasm is immortal. In this germ plasm there is definite structure, so that each part of the future body plasm is localized in the germ plasm in hereditary units, representing either cells or groups of cells that may vary. These hereditary units consist of smaller units, representing the most minute units capable of vital activity. These were called by Weissmann biophors, the hereditary units being called decriminants. A group of decriminants he called an id, the chromosomes of the nuclei being called idants. All these units possess vitality, and are capable of division in the process of increase. In fecundation there is a union of the idant of the spermatozoon and the idant of the ovum, the result being a combination of maternal and paternal idants. In this complex combination the elements follow two courses; some ids become germ cells for the development of other forms of individual life in the future, while other ids break up into decriminants, these again dividing into simple units which represent the cells of the organism. This division takes place largely under the influence of environment, so that the environmental determines which potentiality shall become actual in the future developed life. When it has become a body plasm it cannot again return to the germ plasm, so that the germ plasm cannot be affected by the body plasm, nor can it receive the body plasm characteristics. So that, according to Weissmann, it is impossible to inherit acquired characteristics. Thus the essential principles of Weissmann's theory are two-fold:

(1) That the germ-plasm is not affected by the character of the body-plasm, although originating it.

(2) That the germ plasm remains the same from generation to generation: in fact is immortal.

Why, then, we might ask, do we not find all individuals alike? Weissmann says that the germ plasm does not remain absolutely fixed, but is liable to changes arising from trophic variations, these being the initial changes which finally produce individual characteristics. By the accumulation of such variations, with the variations arising from sexual conditions which we find in the production of every individual life, the blending of two separate and distinct beings, we have the basis of individual characteristics. As soon as the variations become definite, natural selection comes into play to make more definite this individual characteristic. Where these variations remain latent we find the reversion to antecedent characteristics. In the case of regeneration of lost parts, it is assumed that the cells around the lost part have the latent power of regeneration.

Opposed to this theory we find the epigenetic theory, according to which in the fecundated ovum all the parts are alike. Thus the germ plasm consists of a number of quantitative parts, any one of which is sufficient to generate an entire organism, although normally all the parts blend in the production of the organism. According to this theory no predeterminate form exists, the form and function being developed late in the embryonic life—these being determined by the internal reaction of the parts and also by the environment. According to Hertwig, the chief differentiation of organ and function takes place in the localization of the different cells, all the cells being alike till the localization produces differentiation. There seems to be an element of truth in both theories: that there are certain inherent characteristics in the germ plasm sufficient to form a certain predetermination, and that this is modified by the environment surrounding the embryonic life.

SECTION III.—Temperament.

Temperament is the name that is given to certain physical and psychic differences found in individuals, these depending upon variations in the different parts and relations of the organisms, and also upon the changes that take place in the activity of certain parts of the organism. To each individual there belongs a special mode of life which distinguishes him from every other individual. Sometimes the term eccentricity or idiosyncrasy is used to designate the individual temperaments. This is based upon physiological and sometimes pathological conditions. Where we find any particular organ or set of organs predominating, there is a modification of the entire system, producing marked differences in the organization as well as the functions of the organism or of the organs. Where this predominance is established we have the physiological basis of temperament.

In the case of the heart and the blood-vessels being very active, we find a characteristic pulse and also a characteristic complexion, together with a tendency to nervous susceptibility, being easily affected by impressions: in this case we find the psychic condition of imaginativeness associated with quick memory: in some cases this condition becomes pathological, diseases being associated with the blood condition. Such cases were termed by the ancients sanguineous temperaments, and the favorite method of removing the pathological condition, until comparatively recent times, was by bleeding. It was supposed that this condition was produced by an increase of heat and moisture, and it was also claimed that it existed more frequently in the spring season of the year, when on account of the external surroundings the body became more characteristically active, and the mind more energetic. In order to moderate this condition, all that is necessary is to produce a normal equilibration of the circulatory, lymphatic and blood systems, and at the same time to quiet the nervous excitement. Associated with this temperament there were supposed to be the moral qualities of inconstancy and unsteadiness. It was said te be impossible for an individual of a sanguine temperament to give up sensuous pleasures and to set aside those intoxicating ideals that are supposed to be associated with those of an imaginative disposition. This is supposed to depend upon the increased lung capacity and the accompanying increase in the lung interchanges, as well as in the increased circulation of the blood through the heart and body system.

In the case of individuals of this temperament, it is found that by applying themselves to actions that involve the exercise of the muscles there is an increase in muscle size and development, with the result that the sanguine temperament is reduced. In this way the muscular or athletic temperament is developed, with this characteristic: that the body becomes evenly developed, the chest becomes prominent, the shoulders are broadened, and there is a normal proportion between the different parts and tissues of the body. It was from this standpoint that the Greek ideal of athleticism was developed. The Herculean ideal was that of a physical body duly developed in all its parts, and one of the chief ideas associated with the twelve Herculean labors was that by these labors there was the proper adjustment of the different parts of the body—the physical powers and the intellectual functions being exercised to such an extent as to keep both body and mind in a normal condition.

Where there is increased sensibility, particularly if it is associated with what is called a hard pulse, there is a characteristic partially marked muscular condition, and associated with it a passionate temperament. In this condition the

psychic characteristic is that of abruptness and impetuosity, without the even balance which keeps courage within normal limits. From this standpoint ambition represents what the older physiologists characterized as a bilious temperament, in which passion and emotion to a very large extent govern the actions. In this condition the chief characteristics are those of passion, as distinguished from reason, ambition as distinguished from honor. In this temperament it is claimed there is the premature development of the mental as well as the physiological functions. It is supposed that there is associated with this condition undue liver development, and hence an excessive amount of the bile, with the result that the lymphatic and circulatory systems are placed at a disadvantage. In this condition there is the irascibility of temper, such as is associated with the Achillean picture of Homer.

If there is associated with this bilious temperament an abnormal or deranged functional condition of the visceral organs and of the nervous system, so that the vital functions are weakened or interfered with, then we have the melancholic or gloomy temperament. Associated with this we find the sluggishness of digestive action and also of excretory action, the hard and contracted pulse, the unevenness of the mind and the lowering disposition, especially imaginative. This temperament is supposed to be an acquired rather than a primitive or natural condition of the body organism. It is very difficult to describe what is supposed to be involved in this temperament, although it has been claimed that it is more or less associated with all of the great thinkers and poets of the world. Rousseau is taken by some as an example of this temperament. Possessed of a very strong psychic nature, and at the same time of a feeble body, at first open and subject to all of the influences borne to the inner nature through the body mechanism, the mind becomes downcast on account of unhappy conditions and unfortunate circumstances, associated with the individual life as well as the social condition. In his writings we have the evidence of genius struggling against misfortune, affliction and bodily weakness, the physical determining to a large extent not the existence but the sentiments of the psychic. The history of Rousseau seems to prove the fact that this temperament represents a diseased condition, possibly first of the body, and certainly an abnormal condition of the mind.

Where we find the fluids and the solids in disproportion to such an extent that the fluids are excessive, the lymphatic system being especially superabundant, there is found to be an excessive development of the body. At the same time we find accompanying the increase of tissue substance a diffluence of the tissues, accompanied by a weak and soft pulse, expressionless countenance, languid activity and lack of attention from the psychic standpoint. This would represent the lymphatic temperament, in which, on account of the excessive development of the lymphatic system, there is an aversion to that characteristic activity which is associated with the body in its normal physical and psychic condition.

These represent examples of the temperament that is associated with the individual, depending upon the body condition and also the mind condition. There is involved either an increased or a decreased sensibility, and this reacts upon both the physical and the psychic nature. These temperaments are more or less acquired, although in some cases they may be hereditary. The nervous temperament is the one that is most commonly found among individuals in modern times. It is generally acquired, associated with a more or less inactive life; or with a life that is abnormal either on the physical side or on the mental

side. This temperament is manifest in a condition of emaciation in the body, the muscles becoming more or less atrophied, and all the other functions of the body being involved, especially the digestive, secretory and excretory. Sometimes these conditions are spasmodic; at other times they represent continuous conditions that are found throughout the entire course of life.

Those dispositions or temperaments which are based more or less upon physiological conditions are in one sense dependent upon particular body conditions; but they are subject to modifications in connection with habits, manners of life, education, climate, etc. There is no influence that exerts such a modifying effect upon temperament as climate and change of climate. This forms the basis of medical recommendations to change the climate in order to avoid certain pathological temperaments. In all forms of temperament, as we have seen, there is more or less prominence given to one organ or set of organs, so that there is here a deviation from the ideal condition in which all the different parts of the organism are equally balanced so as to produce equilibrium. Where the temperament itself is not, however, abnormal, the equilibrium is not of necessity interfered with, but there is found to be in certain temperaments a predisposition to certain diseases. For example, in the case of those of the nervous temperament there is a predisposition to insanity. In the case of those of a lymphatic temperament there is a predisposition to scrofulous conditions, in connection with which we have the inactivity of the glands, with the result that there is a liquid stagnation, and at the same time there is developed the thickened condition of the cuticle.

SECTION IV.—Old Age and Death.

OLD AGE.—In recent years it has been claimed that decadence begins at birth. As soon as the independent existence has been formed, it is claimed that there is a change taking place in connection with the organism. As growth advances the power to grow becomes rapidly less. This is true in the general sense, because the organic functions are really interrupted to a certain extent from their origin. The totality of the powers of life seems to be diminished from the very starting point of existence. Senescence, however, becomes more marked after fifty or sixty years of age, when there is a gradual decline of the powers of vitality. Those changes represent degeneration and atrophy. In old age the cell changes are marked, the nuclei becoming small and irregular, and the cyptoplasm increasing in size and becoming pigmented. This change is said to be more marked in the brain, for there is a decrease in the weight of the brain, the nucleus becoming smaller and the substance becoming degenerated, accompanied by a decrease in the brain power. There is a decrease in the brain weight from about fifty years onward. This involves a diminution of brain power, both in the origination of impulses and in their conduction along the nerve paths. The sense organs become less sensitive, particularly noticeable in connection with the hardening of the limbs and the enfeeblement of the ciliary muscles, which decreases the accommodation power. There is a general atrophied condition of the muscles, resulting in a loss of strength. Accompanying these is the process of calcification in connection with the tendons, ligaments and arterial walls; the disappearance of the adipose tissue, and fatty degeneration in the cells of muscle and nerve. There is also a decrease in the size of the muscles and an accompanying decrease in the activity of the digestive, secretory and circulatory as well as excretory organs. There is a general decrease in the

size of the organs, although the heart and the kidneys seem to preserve their normal size.

Associated with these changes is the diminshed function of the lungs and the lessening of the excretory products, as well as the diminution of the heart rhythm and the respiration. Two of the most important changes associated with old age are fatty degeneration and calcification. These are found in connection with the cartilages—the cartilage cell simply surrounding fat particles, there being found the calcic phosphates and carbonates, which represent nutritive inactivity. The fatty degeneration seems to indicate that in the tissue decline there is a tendency to revert to the simpler function of fat formation, with the result that we find the fatty degeneration. In most of the system we find the tendency to replace the structural parts by deposits of some kind. This is especially found in connection with the arterial system. In this way nutrition is affected, and at the same time there is an effect upon circulation. In the muscular and nervous tissues this is most apparent. It is claimed that after forty years of age the skeletal muscles begin to lose their dynamic force, and that very soon thereafter the smooth muscle fibres also begin to lose their normal activity. Although the cardiac muscle does not change so much, there is an interference with its activity, diminished force characterizing the heart, the intestines, the bladder, etc. It is in connection with the glandular structures that we find the greatest tendency to preserve vitality. This forms the reason why so often in old age there is the capacity of eating and drinking to a much larger extent than was possible in connection with the earlier stages of life.

The decline is found to take place at the same rate as the development in youth, and from youth upward. Succeeding old age we find actual decay, in which the organ sensibility is lessened, and there is a gradual decline both in the physiological and psychic functions. This is the reason why impression becomes more difficult, judgment becomes uncertain, and the processes that are found associated with the sustenance of vitality are slower and more uncertain. There is an increase in the weight of the bones on account of the accumulated phosphate of lime, with the exception of the skull, which is claimed to become lighter on account of the continued movements upon the internal surface of the skull. In the ossification of the cartilages, particularly of the ribs and vertebrae, the ribs become strongly bound to the sternum, and are thus incapable of performing their normal functions. With the decreased distension of the thorax there is the loss of tone found in the lungs, and the decrease of respiratory activity. The rigidity of the body and the difficulty of moving are not dependent upon the hardening of the ligaments, because the ligaments become relaxed to a considerable extent in extreme old age. Other organs which during development toward maturity became firm, in old age become soft, as in the case of the heart, which in many old people becomes collapsed. The brain becomes indurated, and on this account is more firm and solid, with the result that it is less impressible. This forms the basis of the idea that in old age man returns to a second childhood, in which there is the loss of impressibility, and the organism is reduced to a simple vegetative life. Thus the organism gradually declines and slowly dies, life becoming gradually extinguished, death being the last shade of life.

DEATH.—Sooner or later in the history of life there ensues a change which represents the close of the gradual decline of vitality. Death represents a cessation of all the vital phenomena of the body. Death may be used in reference to the organism as a whole, or it may be applied to the death of the individual

tissues and organs of which it is composed. The body death takes place when one or more of the functions become deranged, resulting in the breaking down and the dissolution of the entire organism. The continuation of a diseased condition of any of the organs of the body, or a simultaneous interference with the functional activity of these organs, either from accident or from disease, may hinder the restoration of that functional symmetry that is necessary to life. It usually results in a failure of action on the part of the heart, the lungs or the brain, or from the death of the blood. Death originating at the heart is called syncope, at the brain coma, and at the lungs asphyxia. The usual sign of somatic death is associated with the cessation of the heart beat, but this is only one of the essential conditions associated with the body death. The muscles and organs of the body may live for some time after somatic death, but gradually they also yield, losing irritability, the muscles becoming stiffened on account of coagulation of the myosin—this phenomenon being called rigor mortis. Throughout the body life there is a constant disintegration of cells, so that death is taking place within the body while life lasts. As soon as the individual life closes the nervous system dies. This is not the case with the muscle tissue. The stoppage of the heart is gradual, the right auricle being the last to die. For some time after death the heart will be found to be irritable, and the smooth muscles of the stomach and intestines will also continue to evidence irritability; the striped muscles continue for a much longer time to be capable of irritation. The glandular cells die very soon. After death the muscles and tissues, when the rigor mortis has passed away, become soft and flaccid—the body being subject to putrefactive changes which result in its dissolution into the elements out of which it was formed.

All tissues, if we except the germ-cell substance referred to in connection with reproduction, pass through this change of death. According to Weissmann, the germ plasm representing the hereditary primitive plasm is immortal and does not die. It is the somatoplasm in which this germ plasm exists that perishes. The body is thus composed of germ cells and somatic cells, the germ cells being transmitted from parent to child. From this Weissmann claims that the original protoplasm was not of necessity doomed to death. Death becomes therefore an acquired characteristic associated with somatoplasm. It has become through acquisition and transmission an established principle of nature that the parent must die in order that the species may continue to live—each birth representing, from this standpoint, a partial death in the reproduction of a new organism. The new organism carries the same life and communicates it from the parent plasm to the child plasm in connection with the immutable germ plasm. This is the invariable order according to Weissmann. Life from this standpoint represents a cycle starting in an ovum and again coming around to an ovum, the animal body being in reality a means for the support and transmission of ova; so that after the parent life has been potentially renewed in the child life, the body of the parent is left to die. On account of the complication of the body mechanism, death is usually a complicated and gradual process. In some cases death comes suddenly, the mechanism breaking down by reason of disorder; but this does not indicate that death itself is abrupt, because when death is natural the system has been becoming enfeebled gradually. The central element of life is the blood circulation. If the blood is normal and kept in normal circulation, life is preserved in connection with the complex mechanisms of life. This complex life consists of the preservation of the circulation, the interchange between the blood and the air, and

the functional action of respiration in connection with the brain. Death may begin at any of these points, but the central point in connection with death is associated with the heart action. Hence death is represened by the cessation of the heart-beat, if that cessation involves inability to recover from the abnormal condition. As we have seen, long before death there is the loss of the reproductive power: after the loss of this power there is the gradual decline of functional life, although the circulation and the respiration continue to be carried on with diminished activity until the very close of life. The brain ceases to receive a sufficient quantity of blood and the muscles lose their contractile powers, while the other organs of the body are not stimulated so as to preserve their normal function. In accidental death it always takes place in connection with the cessation of heart or brain action. In natural death life passes away from the outer parts to the inner, while in accidental death it is from the inner or central to the outer.

In regard to the period of death, there is no great difference in the different parts of the world, whether individuals live in the temperate, frigid or torrid regions. Few people live to a hundred years, natural death coming from seventy-five to ninety years of age. This does not mean that all men live to the same age, for the probabilities of life are very uncertain. Estimates have been made of the probabilities of life. It has been found that about twenty-five per cent of the children that are born die before they reach one year of age: about thirty per cent before they reach two years, and fifty per cent before ten years of age. Two-thirds of the human race die before reaching forty years, and three-fourths before reaching fifty-five years of age. The average of life to a new-born child is about ten years. As the child becomes older the expectation of life increases, so that at the age of seven the probabilities of life are about forty-five years. After this period there is a decrease in the probabilities of life, so that a child at fourteen has only the probability of thirty-five years, at thirty of twenty-five years, and at eighty of one year.

CHAPTER XV. CHEMICAL CONSTITUTION OF THE BODY.

By separating the body into its various parts on the basis of function, we would get the organs of the body. By disintegrating an organ into its simpler structures, we would get the tissues of the body or of its organs. By again reducing the tissues to their constituent principles, so as to destroy all the traces of structure, the principles thus obtained would be the organic or proximate principles of which the tissues were composed. By again disintegrating these proximate principles, so as to find out the elements entering into the composition of these organic principles, we should find the most simple and elementary substances representing the chemical or ultimate elements of the body tissues, such as oxygen, carbon, etc. An ultimate chemical element, therefore, represents a substance which cannot be separated into a more simple form. Of the seventy-two chemical elements at present known, only about fourteen enter into the body composition. These are oxygen, carbon, hydrogen, nitrogen, sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, iron, fluorine and silicon, and possibly manganese and lead. The large proportion of the animal body consists of the first four, these representing about eighty-five percent of the body. These are called organogens. Oyxgen represents the most

abundant element found in existence. Hydrogen represents a chemical element that is never found free in nature. In combination it is found associated with such substances as sugar and starch. Nitrogen represents the most characteristic of the chemical elements in the animal body, being called on this account the fundamental basis of the animal tissue. It forms an essential constituent of the proteids and of the flesh-forming substances, for in the absence of nitrogen the tissues could not be renovated. Carbon is usually regarded as the chemical basis of the vegetable nature, but it is also one of the essential constituents of animal substance. In addition to the organic elements that are essential to the animal body, we find what are called the incidental elements, including sulphur, phosphorus, chlorine, sodium, calcium, and magnesium. The chief mineral compounds of the animal body are sodium, chloride, and calcium phosphate, with calcium carbonate and sulphate together with alkaline carbonates and phosphates.

The different processes that are active in the body are either physical, chemical or vital. To understand the working of these it is necessary to be acquainted with the structure of the body, its anatomy and physiology, and also its relative chemical composition. The changes of the body are so largely chemical that to understand these we must have a knowledge of the body chemistry. Like other living organisms, the human body yields many substances of a highly complex chemical character. The chemical composition of the tissues cannot be determined accurately during life, as chemical analysis destroys their vitality. For these reasons the vital chemistry of the body is only imperfectly understood. The living corpuscles of the tissues are mainly composed of proteids or albuminoids, varying somewhat in composition in the different corpuscles. Thus, while the blood corpuscles may be said to consist of undifferentiated protoplasm, the protoplasm of the muscle corpuscle has undergone some chemical changes in its composition in connection with the specialization of its function, so that it receives the name of myosin. Besides proteid matter, there is present in the body a certain proportion of carbohydrates, fats, saline matters, gases and water, as well as the various substances found between the corpuscles in the tissues which may be regarded a built up by the activity of the corpuscles. There are also waste matters, the products of vital activity. Of these several classes many examples occur, all of which may be reduced to six groups of what are called the proximate principles. A proximate principle is a chemical composition in which compound bodies combined in living matter can be separated as such by purely chemical processes. Hence the proximate principle is an organic compound that enters into the tissue substance; it usually contains the four organogens united together in complex proportion, along with certain quantities of sulphur and phosphorus. Thus sodium chloride is a proximate principle of the body, because it is found in the body as such. Sodium, on the other hand, is not a proximate principle, because, although it exists in the body it is never free as sodium, but always in chemical combination with some other element or elements. For the same reason phosphate of lime is a proximate constituent of bone, but phosphoric acid and chloride of calcium are not proximate constituents, for they do not exist individually in bone, but when united they form the salt. The proximate principles are sometimes divided into two classes, the nitrogenous and non-nitrogenous. The proximate principles of the body may be classed, however, under seven heads: (1) Water. This is present in all the tissues, forming about two-thirds of the weight of the body. (2) Salts. For example, the chlorides and phosphates of sodium and calcium. Sodium chloride is found

in all fluids and tissues, potassium chloride in muscle and other tissues, and calcium phosphates and carbonates in bones and in the teeth. It may be remembered that the sodium salts are found most abundantly in the fluids, and potassium salts chiefly in solids of the body. (3) Gases, carbonic acid, oxygen and nitrogen found in the blood and other fluids. (4) Carbohydrates. Found chiefly in vegetable tissues. Some are found or formed in the animal organisms—(a) grape sugar or dextrine, found to a limited extent in the various fluids of the body, sometimes abnormally large in diabetes. (b) Glycogen or animal starch, in the liver, muscles, etc. (c) Inosit, or muscle sugar, found in small quantities in the muscles of the heart and elsewhere. (d) Lactose or milk sugar, found in milk. Lactic acid is said to be formed from the carbohydrates, as it is found in the muscles and other parts of the body. (5) Fats. The principal fats of the body are formed by the union of a fatty acid with a compound base known as glycerol, a triatomic alcohol consisting of three atoms of hydroxyl, united to a radicle-glyceryl. These are—(a) olein or oleate of glyceryl with oleic acid. (b) Palmatin or palmitate of glyceryl with palmitic acid. (c) Stearin or stearate of glyceryl with stearic acid. The fat of the body exists during life in the fluid condition, and consists principally of olein and stearin. Glycerol is the base present in glycerine, which is the hydrate of glycerol. (6) Nitrogenous substances. These, in addition to C, H, and O, contain N. They are a very important class of bodies, and may be divided into two sub-classes—(a) Proteids or albuminous substances, and (b) substances allied to the proteids. (a) Proteids. These most important substances occur in the animal organism, being complex substances, all containing C, H, O and N, with a small quantity of S. Among them we find myosin, obtained from muscles; globulin, in the red corpuscles of the blood; fibrin, formed when the blood coagulates; casein, found in milk; and the peptones, formed in the stomach during digestion. (b) Substances allied to proteids. These are mucin, found in mucus; elastin, the basis of elastic tissue; kreatin, found in the hair, nails and epidermic scales; neuro-kreatin, found in nervous tissue, chiefly in the brain; gelatin, obtained from the white fibrous tissue, and from bones by prolonged boiling; chondrin, obtained from the intercellular substances of hyaline cartilage by boiling. Both gelatin and chondrin are soluble in boiling water, and the solution of each forms a jelly on cooling. The solution of gelatin gives an insoluble precipitate only with tannic acid and mercuric chloride; but chondrin is also precipitated by acetic acid, mineral acids, alum, lead, nitrate and acetates. Kreatin, kreatinin, xanthin, urea and uric acid, along with numerous other compounds, are products of the breaking down of the nitrogenous substances of the food. (7) In addition to the above groups, there are sometimes classed with the proximate principles the pigments of the body—for example, haemoglobin, the coloring matter of the red blood corpuscles.

The cell life, as well as the tissue functions, depends essentially upon chemical processes. We do not intend to enter into a full discussion of physiological chemistry, because that subject has been discussed in connection with the special chemical actions of the different tissues and organs of the body. This is to be regarded rather as a summary of the relation of chemical action to the physiological functions, because the subject of physiology would be incomplete without taking account of those chemical processes which are so essential to the physiological condition of the body. We cannot tell the true molecular constitution of the vital body, because the constitution of all living bodies is very complicated, and the attempt to analyze living tissues results in such a change in the

molecular constitution as to destroy life. The complexity of the chemical composition of the body is however only a part of the true difficulty, because in order to the preservation of this elaborate constitution they require constantly to pass through chemical changes—these chemical changes forming the basis as well as the fundamental condition of life. The subject of the chemical changes associated with digestion and assimilation has already been discussed in dealing with the physiology of the body. In the tissues of the human body we find a greater variety of substances than we find in the bodies of some of the lower animals; all bodies however are essentially protoplasmic, the special form of this protoplasm being determined rather by the nature of the body than by the chemistry of its constituents.

So essential are the chemical constituents of the body to life, that the removal of one of these elements would mean organic death. In the cells of the body we find the particles so arranged, as when they are all combined together, to constitute life. The chemistry of the body is a material aid to the physiology, because chemical changes lie at the basis of physical activities. Attempts have been made to classify the numerous chemical constituents of the body, but such attempts are uninteresting from the standpoint of physiology, because these classifications do not express the relation of the chemical constituents to the physiological functions. From a physiological standpoint two classifications have been made that deserve to be noticed. Except oxygen, nitrogen and hydrogen, all of the chemical elements are found in compound form—these compounds or proximate principles being classified as (a) organic componnds, and (b) inorganic or mineral compounds. The former include the four chief classes of proximate principles—proteids, albuminoids, carbohydrates and fats—the last two being non-nitrogenous; the latter include water, acids and salts. Another classification that is of importance is based upon the value as well as the vital relation of the substances to the body organism, and particularly the body metabolism—namely, the classificatien into (A) nitrogenous substances. In this classification are included—(1) those compound substances which form the tissues or the different forms of plasm. (2) Those that are called albuminous substances. (3) Albuminoid substances. (4) Substances containing nitrogen, the products of changes in the albuminous substances and the result of tissue metabolism. (B) Non-nitrogenous substances, including—(1) carbohydrates, (2) fats, (3) water, (4) salts.

In discussing this subject we will not attempt to classify the substances, but simply enumerate them one after the other.

1. Plasmic Substances.—

Under this head we find a number of chemical compounds which are unknown to chemistry and physiology, because death destroys the vital conditions of the tissues. As soon as death takes place the substances become dead and are subject to dissociation from the vital relationships. These substances undoubtedly exist as complex chemical bodies, and possess as such special vital properties which give vitality as well as activity to the different organs of the body, motion and activity being essential to tissue life. The most important of these substances is bioplasm. This represents the active substance of all living organisms. It commonly exists in small cell masses, in which we find all of the vital phenomena. While we regard this as a physical and vital substance, we must also assume that it is a chemical compound, because vitality is manifested only so long as chemical integrity is preserved. In the attempt to analyze its

chemical composition, both chemical and vital equilibrium are destroyed. In order to the preservation of protoplasmic vitality, it is essential that the protoplasm be associated with certain substances providing it with warmth, moisture and nutrition. When the chemical and vital equilibrium are destroyed new substances appear, so that we are not able to distinguish the vital substances from the post-mortem substances. In connection with the living body we find another plasmic substance. This plasmic substance is very complex in its composition, as is evident from the fact that accompanying its death we find a number of chemical changes, as well as the appearance of certain albuminous substances that were not known to be present in the plasma during life. The vitality of the plasm is sustained by the changes that take place chemically and physically in the relation of the blood to the body tissues and the external air. In connection with the muscles, we also find a plasmic substance associated with the soft and contractile portion of the striped muscle. This muscle plasma is separated from the muscle at and after death, and, like the blood, is subject to a great many changes, involving coagulation, acidity, change of temperature, and the disappearance of oxygen.

2. THE PROTEIDS.—

These proteids are also called albuminous substances, consisting of organic compounds of C, H, O, N, and S. It is difficult to say whether they exist in this form in the living tissue, because we are unable to analyze them in the living body, the use of any chemical reagents involving death. They are not found in connection with any body secretion, except those which nourish the body or are designed to nourish the germ of life in connection with the ovum, the semen and the milk. They are found in a solid condition, or in solution in the solids and fluids of the body. All of the proteids except haemoglobin, which is really a compound proteid, are amorphous and uncrystalizable. They are not soluble in alcohol or ether, although some are soluble in water and in weak neutral salt solutions, while others can be dissolved only in concentrated salt solutions. Proteids are always present in the protoplasm of living cells, and cannot be separated from organic life. Proteids have been described as "highly complex, and for the most part non-crystalizable compounds of C, H, N, O and S, occurring in a solid viscous condition or in solution in nearly all the solids and liquids of the organism. The different members of the group present differences in physical, and to a certain extent in chemical properties; they all possess however certain common chemical reactions, and are united by a close genetic relationship." The proteids are formed in vegetable life out of simple chemical compounds used as food, while in the animal life the proteids are taken directly or indirectly from the vegetables. In connection with the action of the digestive juices, the proteids are converted into peptones, and after absorption become reconverted into proteids. In connection with these albuminous bodies we find several classifications—(1) Native albumins; these represent proteids which can be dissolved in water and cannot be precipitated by saturation with sodium chloride. They may be coagulated by heat. The chief of these are egg albumin, which is not obtained in ordinary tissues but is found in the white of an egg; serum albumin, which is found as the albumin is formed in the nutrient fluids of the body, and also lactalbumin. (2) Globulins: these proteids are not soluble in water, but are soluble in dilute neutral salt solutions, and may be precipitated by saturation with sodium chloride. These are coagulated by heat. The chief classes of globulins are serum globulin, which is found in connection with the tissues, and

the blood fibrinogen, which is found in connection with the blood; myosin, which is obtained from dead muscle in connection with the exudation from the muscle clot; crystallin, globin and vitellin. (3) Derived albumins or albuminates. This name is given to the metallic proteid compounds, and also to the syntonin or acid albumin, which is derived from the regular proteids by the slow action of weak acids or the rapid action of a strong acid; it is also applied to the alkali albumin, which is produced by the action of a weak alkali or a strong potassium solution in connection with egg albumin. These two are proteids insoluble in water or in neutral salt solution, but very soluble either in dilute acids or alkalies. The solutions cannot be coagulated by heat. The casein of milk is also a proteid precipitated from the milk by rennet or by strong acetic acid. (4) Proteoses. These represent proteids which are not coagulated by heat, but are precipitated by saturation with neutral salts or with nitric acid, the latter precipitate being dissolved by heat. They are like the peptones in their capacity of diffusibility. They are formed from the proteids by proteolytic action representing an intermediate stage in peptone formation. The chief of these are albumoses, among these being proto-albumose, hetero-albumose, and deutero-albumose. (5) Peptones. These proteids are formed by the action of the digestive ferments and are very soluble in water, not being precipitated by heat or by a neutral salt solution or by nitric acid. The peptones are sometimes subdivided into hemi-peptones, which under the action of pancreatic digestion yield leucin and tyrosin; and anti-peptones, which do not yield those substances. (6) The insoluble proteids. In this class are included a number of proteids—for example, fibrin, which is only known in connection with the chemical changes involved in the death of the blood plasma; coagulated proteids, gluten. These proteids differ from the others in the sense that when coagulated they lose their former characteristics. The proteids possess some general characteristics. Among these are (1) their non-diffusibility. The peptones and also the albumoses are however diffusible. On account of their indiffusibility we are able to separate the proteids from saline mixtures, and also to separate the proteids from one another. (2) The proteids are all characterized by this: that they "rotate the plane of polarized light to the left." (3) Most of the proteids may be coagulated by heating, although there is a difference in the temperature at which coagulation takes place—myosin and fibrinogen at 56 degrees, egg albumin at 72 degrees, and globulin at 75 degrees C.

3. The Albuminoids.

This term is limited to certain nitrogenous substances very closely allied to the proteids, differing from the proteids, however, in some respects. These represent the result of nutritive changes in the protaplasm, and may be said to be produced by it so as specially to adapt the substance to the requirement of some of the tissues. Among these substances we find mucin, which is associated with the secretion of some of the epithelial cells, and the chief part of the substance of connective tissue. It renders the fluid viscous and is precipitated by acetic acid. Mucin is the chief element of mucus, and gives the ropy characteristic to the secretion, being suspended in an alkaline exudation from the blood and mingled with broken-up epithelial cells. In connection with the mucous glands, such as the sub-maxillary, we find the mucin. Among other albuminous substances we find collagen in connection with the white fibres of connective tissue, including tendons and ligaments. Ossein is also derived from the bone. Collagen when boiled is converted into gelatin, which represents the most character-

istic albuminoid substance, becoming a jelly when allowed to cool after boiling. It is very easily digested, but it cannot take the place of the proteids, except in saving the proteids. In conjunction with proteids, even if the proteids are very small in quantity, gelatin can sustain nitrogenous equilibrium, and also lessen the amount of waste that is associated with the use of fat in the body. Among the other albuminoids we find chondrin, which is formed by prolonged boiling of cartilage, being probably mixed with mucin and gelatin. We also find elastin in connection with the boiling of the yellow elastic tissue with caustic alkali. Nuclein is the principal constituent of cell-nuclei; nucleo-albumin represents a compound of proteid and nuclein, and is found in connection with cell protoplasm. Keratin is found in the epidermic appendages, and is found to consist of a large quantity of sulphur, being soluble in the alkalies and very insoluble in the digestive juices.

4. THE CARBOHYDRATES.—

These are compounds of C, H, and O, two atoms of H being found for every atom of O, in the molecule. They are taken chiefly from vegetable tissue and are very important as foods, although some of them are found in connection with animal tissue, such as grape-sugar, milk-sugar and glycogen. They have been arranged in three groups: (a) the amylose or starchy carbohydrates. The chief amyloses are starch, which is found in small granular masses in some plants, and is changed by the fermentation of the salival and pancreatic juice into dextrin and maltose by a hydrolytic process; dextrin, which is intermediate between starch and sugar; glycogen or animal starch, which is found in the liver and in the muscles. The liver seems to get its carbohydrate in dextrose form, storing it as glycogen, reconverting it again into dextrose by hepatic cell activity; cellulose represents a colorless substance found in the cell wall of plants and of grains like corn, oats, etc; (b) the glucose group includes the dextrose or grape sugar found in connection with fruit, honey, and in small quantities in the blood; laevulose, the sugar found in connection with some fruits and formed along with dextrose from cane sugar by invertin action; galactose or the sugar that is formed by lactose hydration; and inosit, or the muscle sugar. (c) The saccharose group includes cane sugar found in fruits and in plant juices. When used as food it is inverted into equal parts of dextrose and laevulose by fermentation; lactose, or the milk sugar, and maltose, or the starch form of sugar formed in connection with ptyalin and amylopsin action, and also formed by diastasic action upon starch.

5. FATS.—

Fat consists of C, H and O, the oxygen being less in proportion to the hydrogen than in connection with the carbohydrates. Fats are found in large quantities in some tissues, and also suspended in most of the fluids. It is said that the average amount of fat is about one-thirtieth part of the body. Fats are found in the three forms, palmitin, stearin and olein—the first two being liquefied on admixture with olein. Fats are not soluble in water, but are soluble in ether and alcohol. The fats are compound substances composed of glycerin and fatty acids, water being removed in the process of combination. In connection with sodium hydration there is a splitting up of the fat into glycerine and a compound of the fatty acid and an alkali, called a soap, representing the process of saponification. When fats are shaken up in connection with water containing albuminous substances or a solution of alkaline carbonate, the fluid

fat is broken up into fine particles forming an emulsion. Milk represents an emulsion. Saponification and emulsification take place in connection with the alimentary process, steapsin saponifying a part of the fat, the soap assisting the pancreatic juice, and the bile in the emulsification of the rest.

6. THE FERMENTS.—

Fermentive action is the essential basis of the digestive process, chemical changes being induced in connection with a ferment. As distinguished from the organized ferments which are associated with the micro-organic action, we find the unorganized ferments or enzymes which are associated with the fermentation processes that take place in the alimentary canal. These have been classified as amylolytic, changing starch and glycogen into sugar, as in the case of ptyalin, and amylopein; proteolytic, changing proteids into proteoses and peptones, as in the case of pepsin and trypsin; steatolytic, splitting up the fats into glycerine and fatty acids, as in the case of steapsin; invertin, converting the saccharoses into the assimilable form of dextrose; the coagulating ferments, which convert soluble into insoluble proteids, as in the case of rennin changing caseinogen into casein; fibrin ferment, changing fibrinogen into fibrin; and the myosin ferment that coagulates myosinogen. Ferment action is associated with a hydrolytic process, in which water is added to the substance that is acted on, resulting in the formation of new substances.

7. THE PRODUCTS OF TISSUE CHANGE.—

In the metabolic processes of the tissues, the tissues go through certain processes involving the assimilation of certain substances, and the breaking up and throwing off of certain other substances, which are found in connection with the secretions and excretions. In connection with the bile we find two acids united with sodium to form soluble salts, which can be identified by the purple-violet color produced by cane-sugar at a temperature of 70 degrees C. These are taurocholic and glycocholic acid. In the bile we also find the coloring substances bilirubin and biliverdin—the former being found in the human subject, and being derived probably from the coloring matter of the blood. Lecithin represents a complex nitrogenous fat found in connection with the fluids and the tissues of the body, particularly in nerve tissue. It is chiefly found as a decomposition product of the brain substance. Cerebrin is also obtained from the brain substance and the nerve substance—the only thing that is known being that it does not contain phosphorus. Protagon is supposed to be the principal substance found in the brain, and is said to be a combination of lecithin and cerebrin. Cholesterin is found in connection with tissue changes and metabolism, particularly in connection with the nerve centers. It is also obtained from gall-stones, and seems to be amonatomic alcohol. In connection with the waste matters that are thrown off from the body as the result of the active chemical changes that take place in the body, we find urea, uric acid, kreatin, kreatinin, leucin, tyrosin, indol, indican, etc., which have been considered before.

8. SALTS AND ACIDS.—

Inorganic acids are found either in combination in the formation of salts, such as sulphuric and phosphoric, or in an uncombined condition, as in the case of hydrochloric acid, which is formed in connection with the mucous glands of the stomach in the marginal cells, and has an important function to discharge in connection with gastric digestion. We also find carbonic acid gas in nearly all

fluids of the body, being absorbed from the tissues during the process of combustion. A large quantity is found in connection with the plasma of the venous blood, which as it passes through the lungs eliminates the gas in connection with expiration. Many salts are found in connection with tissue in small quantities. In the teeth and the bones the salts are found in solid form, and in larger quantities than in the softer tissues where they are found in solution. Most of the salts are taken into the body in the form of food, although some may be formed in the body. We are unable to say what position is occupied by the salts in the living animal tissue, because we can only estimate the quantity from the ash of the tissue found after burning. They are doubtless in chemical combination with some of the complex organic substances, and are necessary to the performance of the body functions. In what way they assist in the body functions we are unable to say, except that they seem to assist in the solution of certain substances like the globulins. Sodium chloride is the most common salt found in the body, and is found in large quantities in all the tissues and fluids except the bones, the teeth, the red corpuscles and the red muscle. Small quantities of potassium chloride are found along with the sodium chloride, and larger quantities in muscle and the red corpuscles. Carbonates and phosphates of calcium, sodium, potassium and magnesium are also found in the tissues.

(9) Water is found in nearly all the tissues of the body, in larger proportion than any other chemical substance, representing about 75 percent of the body weight. Water is taken into the body in drink and along with the more solid food. There is also, as we have seen before, the formation in connection with the tissues, water being formed by the oxidation of the hydrogen found in connection with the more compolex substances that are found in the body. When water is absorbed in connection with a substance, we have a hydration process, as in the case of calcium oxide transformed into hydroxide in connection with water. The breaking down of substances by the absorption of water is called hydrolysis, as in the case of cane sugar absorbing water and being broken up into dextrose and laculose. The importance of water in the digestive process may be estimated from this fact: that all the fermentation actions really take place in connection with hydrolysis. Water in connection with the body system acts as a solvent, and as the means through which chemical changes take place in the different organs of the body, as well as forming the chief constituent of the body substance.

10. The Coloring Matter and Pigments of the Body.—

These coloring matters of the body are essential constituents of the body substance. Among these we find haemoglobin, which represents the principal constituent of the red corpuscles which give the dark color to the venous blood. In the ordinary arterial blood it is also present in small quantities. On the exposure of haemoglobin to the air it quickly unites with oxygen, becoming oxyhaemoglobin, the chief constituent of the red corpuscles in the arterial condition. Haematin represents a disintegration product of haemoglobin under the action of oxygen. When reduced haemoglobin is heated in sealed tubes free from oxygen, along with dilute acids of alkalies, there is produced a purple-red compound called haemochromogen, which represents a disintegration product of haemoglobin. On exposing the blood for a time to the air and examining it by the spectroscope, it is found to exhibit, in addition to the oxyuaemoglobin, absorption bands—a marked absorption band which is due to methaemoglobin. In connection with the bile we find the bilirubin, representing the coloring matter

of the ordinary yellow human bile. There is also found sometimes another oxidation product called the green coloring matter biliverdin. In connection with the skin, the retina and the iris, we find melanin, containing iron and originating in connection with the haemoglobin. In the pathological condition of melanosis we find the deposition of black granules. There is sometimes found a disintegration product of hemipeptone in triptic digestion, called triptophan. These represent the most common substances that are found in connection with the coloration of the different tissues and substances of the body.

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